NASA CR 70580

FACILITY FORM 602

N66-18321

(ACCESSION NUMBER) (THRU)

32

(PAGES) (CODE)

1

CR 70580 30

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

GPO PRICE $

CFSTI PRICE(S) $

Hard copy (HC) 3.00

Microfiche (MF) .75

653 July 65

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

S/133940 K

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

RE-ORDER NO. 64-965

M-49-64-2
15 SEPTEMBER 1964

ASTEROID BELT AND JUPITER FLYBY STUDY

FIRST BIMONTHLY PROGRESS REPORT

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

ASTEROID BELT & JUPITER FLY-BY MISSION STUDY

6 MONTH FEASIBILITY STUDY

CONTRACT NO. 950871

1ST BI-MONTHLY PRESENTATION

SEPT 15, 1964

INTRODUCTION AND SUMMARY

This brochure represents a summary of work performed to date by Lockheed Missiles and Space Company on JPL Contract No. 950871. The overall objective of the Study is to determine alternate ways of reliably accomplishing a scientific investigation of the Asteroid Belts and the planet Jupiter, utilizing unmanned spacecraft. The scientific objectives include measurement of particle distribution in the Asteroid Belts, physical and chemical properties of asteroidal material, observation of the gross surface features of a major asteroid and measurement of Jupiter's environment.

The first two months of the study have been devoted to selecting suitable experiments, the analysis of mission profiles and energy requirements, the development of subsystem concepts and preliminary estimates of the spacecraft configuration. During the second phase, trade-offs will be performed to allow selection of the final concepts. The final phase will involve a detailed analysis of the chosen concepts resulting in final descriptions of the mission, scientific payload, subsystems, vehicle configurations, functional specifications, reliability aspects, development programs and cost.

The planning of the scientific experiments has received major emphasis during Phase I. Only very limited data exist on the properties of the Asteroids and Jupiter; this implies a wide field for future effort but also limits the planning of experiments based on current reliable theory. The approach taken was to define all desirable observations and apply a scientific priority to each. Implementation of the experiments was then studied and a final project priority awarded to each experiment. The latter operation included consideration of ease of measurement, instrumentation complexity, data storage and retrieval, as well as scientific priority. The results are summarized in tabular form on pages 17 to 27. Preferred experiments include observation of the following:

Asteroid Belt: Flux and size distribution of particles, mass distribution
physical and chemical properties.

Major Asteroid: Mass and surface visual features.

STUDY OBJECTIVES

DETERMINE ALTERNATE FEASIBLE WAYS OF MEASURING

- PARTICLE DISTRIBUTION IN ASTEROID BELTS FOR
  - 1-VEHICLE DIA.
  - 100-VEHICLE DIA.
- PHYSICAL AND CHEMICAL PROPERTIES OF ASTEROIDAL PARTICLES
- GROSS SURFACE FEATURES OF ONE MAJOR ASTEROID
- ENVIRONMENT OF JUPITER
  - MAGNETIC FIELD
  - RADIATION
  - ATMOSPHERIC PRESSURE, TEMPERATURE, COMPOSITION
  - SURFACE TEMPERATURE
  - VISUAL

Jupiter:	Magnetic field, trapped particles, atmospheric composition, thermal balance, radio emission, auroral effects and dust concentration.

Inspection of a major Asteroid should be carried out with (1) Ceres and (2) Vesta. The choice of Ceres as a prime objective is based mainly on size consideration (for maximum spacecraft trajectory perturbation in mass determination experiment). Vesta has a higher value of albedo but calculations of the light intensity near Ceres show that it is adequate for conventional T.V. pictures.

Mission Concepts have been proposed to meet the experimental requirements (see page 14). Although multiple missions are desirable for a thorough investigation, the following are recommended if the choice is limited to single missions.

Asteroid Belt:	Fly-through all belts, aphelion at 4 to 5 A.U.
Major Asteroid:	Light-side flyby
Jupiter:	Light-side flyby with terminal orbit inlined about 20-30 to Jupiter's equator.

A flyby of Jupiter at 2 radii is desirable for magnetic field and trapped radiation measurements. A restriction on miss distance might be imposed by Jupiter's environment (strong magnetic field, intense radiation and dust concentration) but preliminary investigations indicate that these factors can be overcome by suitable spacecraft design. A composite mission consisting of a Belt fly-through, flyby of a major Asteroid and a flyby of Jupiter appears attractive, but for the major asteroids examined (Ceres, Vesta and Juno) no such opportunity exists, because the Asteroid orbits are inclined to the plane of the ecliptic.

Heliocentric ephemeides have been calculated for all objects of interest and trajectory analyses have produced the following data.

Earth-Jupiter transfers for opportunities in the period 1970-1980 (page 39)

Time history of a heliocentric ellipse to the Asteroid Belts (invariant with time)(page 48)

SUBSIDIARY OBJECTIVES

- ALTERNATE EXPERIMENTAL CONCEPT DESCRIPTIONS (TECHNIQUE, INSTRUMENTATION, WEIGHT, POWER, ETC.)
- SELECT OPTIMUM MISSIONS
- TRAJECTORY ANALYSES (LAUNCH WINDOWS, ENERGY REQUIREMENTS, ETC.)
- SUBSYSTEM REQUIREMENTS
- SPACECRAFT CONCEPTS
- RELIABILITY
- TRADE-OFFS AND PROBLEM AREAS
- LAUNCH SYSTEM CONCEPTS
- FUNCTIONAL REQUIREMENTS
- DEVELOPMENT PROGRAM AND COST

Earth-Ceres and Earth-Vesta transfers for opportunities in the period 1970-75 (page 53)

Long trip duration is a characteristic of all missions involved in the study; thus reliability will be a major design consideration. Minimum-energy Jupiter missions show only moderate yearly variation in energy requirements, with 1970 the most favorable year. However, at each opportunity, the energy requirement varies considerably with trip duration. Thus increasing the duration from 470 to 830 days reduces the launch velocity requirement by 7000 ft/sec. Also the energy-duration dependence places strict limits on the launch window. The Asteroid flyby missions show considerable differences from opportunity to opportunity. When work is completed on the Asteroid transfers, optimum launch dates will be selected for each target Asteroid. Other work in the field of space flight mechanics has been concerned with the characteristics of Jupiter-centered hyperbolas for various hyperbolic excess speeds and Jupiter pericenters, and the computation of guidance sensitivity coefficients for the Jupiter missions (1970-80).

Spacecraft subsystem requirements have been studied and preliminary concepts developed. Extension of Mariner guidance techniques should be suitable for all missions. Exclusive Earth-based radio tracking (DSIF) is being considered with one or two midcourse corrections, depending on mission requirements. Miss distances of approximately 1000 and 2000 km at Ceres and Jupiter, respectively, can be achieved with one correction. Requirements for observations of one of Jupiter's satellites will present additional guidance problems (terminal correction to include arrival time adjustment) and some launch window restrictions. The Sun-Canopus system will be used for stabilization reference, and reaction jet controls will be used. Continuous stabilization (except during maneuvers) is presently being considered. The occultation of the Sun when very near Jupiter may pose a problem. This might be solved by choosing a suitable terminal trajectory ("light-side) or acquiring a new reference (the planet), although the latter technique is far from desirable.

Data handling techniques will involve storage in all cases - due to the high acquisition rates during the Asteroid and Jupiter encounter, whereas in the Asteroid belts accumulation of data is required to utilize the data transmission link efficiently. A steerable, 7 ft dia, parabolic antenna is suggested

STUDY GUIDE LINES

- MISSION PERIOD:
  - ASTEROID BELT 1967 - 75
  - LARGE ASTEROID AND JUPITER FLYBY 1970 - 75
- REALISTIC INSTRUMENTATION
- FULL DSIF TO BE UTILIZED
- LAUNCH VEHICLES:
  - ATLAS AGENA D
  - 30% FLAX ATLAS - CENTAUR + APPROPOIATE 3RD STAGE

for the Jupiter mission. Operating at 10W all the experimental data (exclusive of TV) could be transmitted in about 19 hours. A requirement for TV information imposes more stringent requirements, as approximately 18 hours are required for the transmission of each frame. Transmission delay times (about 40 min at Jupiter, 20 min at Asteroid) adds to operating power requirements since some three times this period is required to ensure coherent operation of the link. Jupiter's radio noise reduces the bit rate received at Earth and will probably eliminate the possibility of spacecraft reception within about 3 to 4 Jupiter radii.

Preliminary power profiles for the missions indicate an average peak load of about 200 watts. A radio isotope power source will be required in all cases. A SNAP-9A system (1 watt per lb) is presently being considered. Solar panels could be used on the shorter-duration missions but large areas are required and severe damage from asteroid particles can be expected (see Page 65).

A detailed design of the spacecraft is contingent upon a detailed statement of scientific instrumentation and subsystems. As this information is not available at this stage of the study, only preliminary concepts have been generated (see pages 75 and 77). Preliminary payload estimates (total spacecraft) indicate values of 1165, 1150 and 1350 lb for the Asteroid Belt, Major Asteroid and Jupiter missions, respectively. This means that the Flox Atlas-Agena and Flox Atlas-Centaur launch vehicles alone will not be adequate. A high energy kick stage combined with the Flox Atlas-Centaur vehicle will be required. Even so, the Jupiter mission will be limited to relatively long duration trips. The possibility of using other launch systems (such as Saturn 1B-Centaur) should be given consideration.

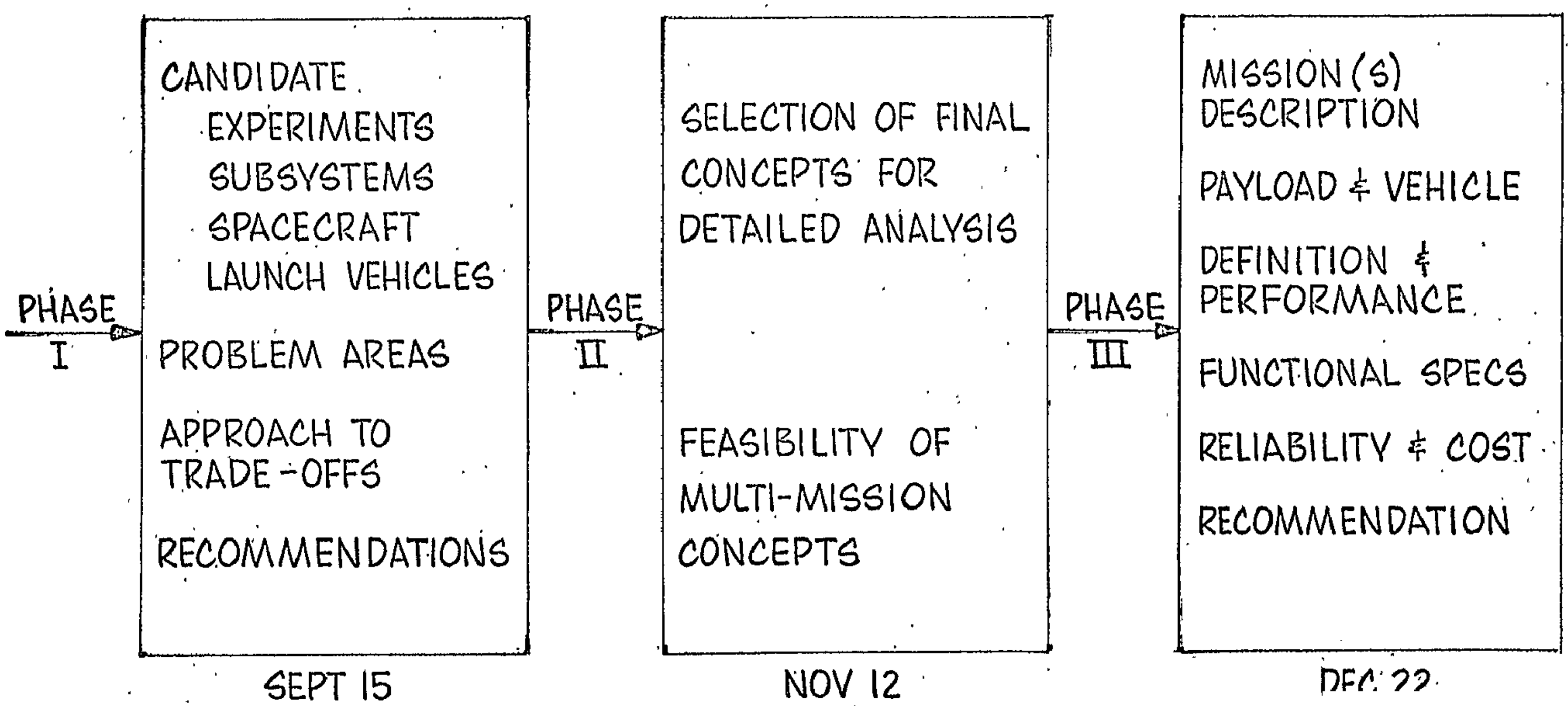
The data reproduced in this brochure were given in chart form at the first Bimonthly Oral Presentation at JPL on September 15, 1964.

Phase II Study Plan

During the next two months of the study, the technical effort will be directed toward further analyses and trade-off studies to achieve the following objectives:

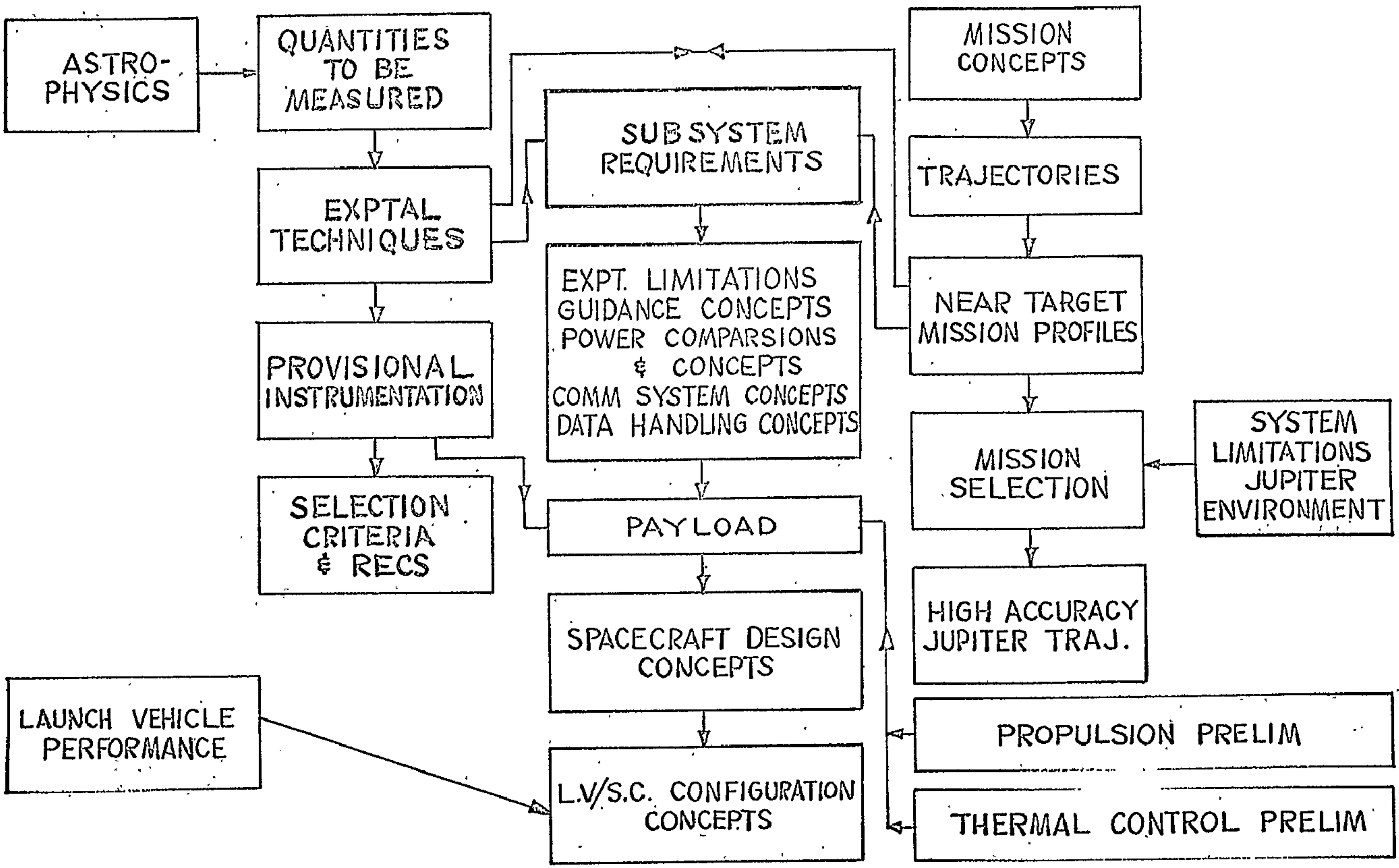
- Selection of experiments that will provide most valuable data for each mission (within the restraints imposed by subsystem capability and launch vehicle potential)

STUDY PLAN


PHASE I
CANDIDATE
EXPERIMENTS
SUBSYSTEMS
SPACECRAFT
LAUNCH VEHICLES
PROBLEM AREAS
APPROACH TO TRADE-OFFS
RECOMMENDATIONS
SEPT 15
PHASE II
SELECTION OF FINAL CONCEPTS FOR DETAILED ANALYSIS
FEASIBILITY OF MULTI-MISSION CONCEPTS
NOV 12
PHASE III
MISSION (S) DESCRIPTION
PAYLOAD & VEHICLE
DEFINITION & PERFORMANCE
FUNCTIONAL SPECS
RELIABILITY & COST
RECOMMENDATION
DEC 22

- Detailed analysis of required instrumentation and definition of scientific payload
- Finalization of appropriate mission concepts
- Completion of trajectory analyses for Ceres and Vesta and preparation of contour maps; compilation of launch window data for all missions
- Computation of a limited number of high-accuracy interplanetary trajectories to supplement performance estimates obtained from the Medium Accuracy Orbital Transfer program
- Influence of reliability considerations on instrumentation and subsystems
- Definition of recommended subsystems (thermal control, midcourse propulsion, guidance and control, data handling, communication and power supplies)
- Finalization of candidate spacecraft concepts and compatible launch vehicle
- Preparation of functional specifications
- Feasibility of multi-mission concept (standard bus)

PHASE 1 STUDY PLAN



PROPERTIES OF 3 MAJOR ASTEROIDS

	CERES	JUNO	VESTA
PHYSICAL:			
DIA (KM)	700	220	380
MASS	$10^{-4} M_{\oplus}$	$0.33 \times 10^{-5} M_{\oplus}$	$0.17 \times 10^{-4} M_{\oplus}$
ROTATION PERIOD	9H 05M	7H 12M	5H 20M
ALBEDO	3.2 - 6.0	11.5 - 12.0	25 - 26
ABS. MAG	4.0	6.3	4.2
COLOR INDEX	0.5	0.83	0.55
LIGHT VARIATION (MAX)	0.04 MAG	0.15 MAG	0.13 MAG
ORBITAL:			
SEMI-MAJOR AXIS (AU)	2.767	2.670	2.361
SIDEREAL PERIOD (YR)	4.60	4.36	3.63
ECCENTRICITY	0.079	0.256	0.088
INCLINATION TO ECLIPTIC (DEG)	10.6	13.0	7.1

PROPERTIES OF JUPITER

PHYSICAL

DIAMETER	$10.97 \times D_{\oplus}$
ROTATION PERIOD	9HR. 50MIN
MASS	$318.35 \times M_{\oplus}$
DENSITY	1.35 GM/CM^2
ATMOSPHERE	H_2, He, CH_4, NH_3 TURBULENT MOTION, BELTS AND SPOTS
INTERIOR	CORE METALLIC H, CONTINUOUS CHANGE OF PHASE TO ATMOSPHERE
RADIATION BELTS	POSSIBLY $1000 \times \oplus$ TO $3R_{♃}$
RADIO EMISSION	DECAMETRIC - BURSTS, CIRCULARLY POLARIZED DECIMETRIC - CONTINUOUS, PLANE POLARIZED
TEMPERATURE	$\sim 130°$ K (CLOUDS)
SATELLITES	12 (4 LARGE)

ORBITAL ELEMENTS

SEMI MAJOR-AXIS	5.203 A.U.
SIDEREAL PERIOD	11.86 YR.
SYNODIC PERIOD	399 DAYS
ECCENTRICITY	0.048
INCLINATION TO ECLIPTIC	1° 18.5'
MEAN ORBITAL VELOCITY	13.06 KM/SEC.

MISSION CONCEPTS

ASTEROID BELT

1. FLY-THRU, APHELION 2.3 AU
2. FLY-THRU, APHELION 3 AU
3. FLY-THRU, APHELION 4 AU

*4. FLY-THRU, APHELION ♃ ORBIT

5. OUT OF ECLIPTIC FLY-THRU
6. NEAR CIRCULAR ORBIT IN MAJOR ASTEROID BELT

MAJOR ASTEROID

*1. LIGHT SIDE 2. DARK SIDE	VARIOUS CHOICES OF ASTEROID

JUPITER

*1. LIGHT SIDE 2. DARK SIDE	VARIOUS INCLINATIONS TO ♃ & CHOICE OF MISS DISTANCE

COMPOSITE

*1. FLY-THRU BELTS & FLY-BY ♃

*2. FLY-THRU 1ST BELT & FLY-BY ASTEROID

3. FLY-THRU BELTS, FLY-BY ASTEROID AND JUPITER

PLANNING OF EXPERIMENTS

DESIRED SCIENTIFIC OBSERVATIONS: ASTEROID BELT AND JUPITER EXPLORATION MISSIONS

In general, the present state of knowledge about the Asteroid Belt and Jupiter is poor; many observations (particularly of Jupiter) have yielded information which has not yet been theoretically interpreted. A hundred years of observation of Jupiter's clouds has not led to a general theory of the Jovian atmospheric circulation.

The following tables summarize the areas in which valuable information could be obtained and rank the desired observations in classes of scientific priority. The range of measurement refers to the conditions under which the observations should be made.

The estimated scientific priority is a preliminary judgement on the value of the information and reflects the needs of a variety of disciplines. A high priority (Class 1) may be awarded on several bases. For instance, well-defined measurements likely to give clear positive results that can be used to test current theories have been assigned a high priority. Measurements that might be correlated with well-known terrestrial phenomena (e.g. Jupiter's radiation belts), or might be needed for future space missions (e.g. meteoroid concentrations) are also considered important. Special consideration has also been given to experiments that are extremely difficult or impossible to do from Earth (e.g. Jovian dark-side phenomena) and observations that would fill obvious gaps in the present body of knowledge.

A low priority (Class 2 or 3) has been given to undefined exploratory experiments which might be difficult to interpret and to special phenomena peculiar to the Asteroids or Jupiter which might have no relevance to the rest of the solar system, or even to the overall structure of the system of minor planets or Jupiter.

DESIRED SCIENTIFIC OBSERVATIONS
ASTEROID BELT

Quantity to be Measured	Present Status	Range of Measurements	Scientific Priority
Particle distribution in Asteroid Belts	Only small area detectors have been flown near Earth.		
a. Flux (density) distribution		a. Unknown	1
b. Size distribution		b. 1μ to 1 km dia.	1
Physical and Chemical Properties of asteroid material.	No data available.	Unknown	1
Velocity distribution of Asteroid Material	Data only on large asteroids.	5 to 12 km/sec rel. to S/C	2
Mass distribution of asteroid material.	No data available.	10^{-14} to 10^{14} gm.	1
Interplanetary environment	Avail. equipment.	Particle radiation and plasmas	2
		ASTEROID FLYBY	
Gross surface features of a major asteroid	No data available	1 km recol. on large body	1
Mass of asteroid	No reliable data available	$M > 10^{-5} M_e$	1
Axis and rate of rotation	Estimated from photometer measurements	Rate $> 10^{\circ}$/hr	3
Surface temperature distribution	No data available		2
Composition	No data available		2
Interplanetary environment	Equipment available	Meteoroid detector	3

DESIRED SCIENTIFIC OBSERVATIONS: JUPITER ENVIRONMENT

QUANTITY TO BE MEASURED	PRESENT STATUS OF KNOWLEDGE	RANGE OF MEASUREMENT	SCIENTIFIC PRIORITY
<u>Radiation Belts</u>			
Magnetic fields; intensity and direction	Inferred from radio emission, may be 1000 gauss at surface; N-S assymmetry	$<1\ R_{♃} - 100\ R_{♃}$ $H = 10^{-4} - 10^{3}$ gauss	1
Trapped electron flux, energy spectrum, pitch angle distribution, and spatial extent	Inferred from radio emission; may be 10^{3} x intensities in earth's trapped radiation belts	$<1\ R_{♃} - 10\ R_{♃}$ E = 100 ev-100 mev Flux $<10^{8}$ cm^{-2} sec^{-1} (E>100 kev)	1
Trapped proton flux, spatial extent	Not established	$<1\ R_{♃} - 10\ R_{♃}$ E> 100 kev Flux unknown	1
<u>Atmospheric composition:</u>			1
Visual and ultraviolet search for H, He, Ne, N, N_2, O_2, O_3.	Spectra from 3000 to 10,000 Å show CH_4, NH_3, H_2; Obscuration in infrared by earth's atmosphere constituents	1000 - 6000 Å	
Infrared search for H_2, N_2, H_2O, CO, CO_2, OH, free radicals, trace constituents		6000 - 80,000 Å	
Microwave spectra of free radicals and trace constituents		0.1 - 2 cm	
Direct composition determination by atmospheric probe		100 - 200 km above clouds	
<u>Atmosphere temperature/pressure/density structure:</u>			
Direct density measurement by atmospheric probe	Radiometers yield temperatures 120 - 200° K for atmosphere above clouds. Scale height ≈ 8 km.	Above clouds	2
Temperature measurement by line or band shape		Above strongest absorption	2
Scale height or molecular weight from light extinction		High atmosphere	2
<u>Surface - atmosphere temperatures and radiation balance:</u>			
Radiometer scans of planet at several wavelengths including bands of NH_3 and H_2O	120 - 200°K. Satellite shadow effects seen at 10 micron; details not resolved at longer wavelengths	Entire planet, including terminator and red spot	2
Far infrared spectrum including most of thermal radiation to determine radiation balance	Jupiter may emit more radiation than it absorbs	5 - 100 micron	1

Surface - cloud structure:			
Visual-infrared observation of atmosphere circulation cloud structure, red spot circulation	Best resolution available resolves 3000 km; no theories of circulation except for red spot which may be Taylor column.	3000 Å - 10 micron	3
Radar reflection from surface to observe surface roughness and structure	Perhaps no sharp transition between "surface" and atmosphere; red spot may be caused by surface irregularity.	Frequency>20 mc.	2
Ionosphere and radio sources:			
Monitor of 18 - 20 mc radio bursts to determine variation with Jovian time	Source may be localized on surface; time variations may be due to ionosphere or sun, rotation effects not separated.	$\Delta t = 1$ sec.	2
Search for x-rays correlated with radio emission	Undiscovered, may be produced by mechanism responsible for radio bursts	$\Delta t = 1 - 10$ sec 2 - 10 Å	3
Radio transmission measurement of ionospheric electron densities	Ionosphere inferred from radio emission; may have electron densities much larger than on earth, may be thick.	Frequencies>18 mc	1
Nightsky and auroral emissions:			
Ultraviolet-visual search for auroral emission	May be inferred from presence of magnetic field and trapped particles	Darkside 3500 - 11,000 Å	2
High sensitivity record of night sky spectra	May be inferred from emissions on earth	Darkside 3500 - 11,000 Å	2
Search for twilight Na (D) and N_2 emission	May be inferred from emissions on earth	Terminator	3
Distribution of Lα emission around planet	Probably trapped in extensive hydrogen atmosphere	0 - 10 $R_{♃}$?	3
Jupiter's satellites			
Determination of surface roughness from variation in light scattering with phase angle	Albedos poorly known, only for backscattering	approach to satellite; visual light	2
Resolution of surface details of one satellite by visual observations	Nothing known ?	within 50,000 km of satellite	2
Search for atmospheric constituents in spectra	Atmospheres not yet discovered; largest satellites large enough to hold heavy gases (CH_4)	approach to satellite; 5000 - 10,000 Å	2
Micrometeorites:			
Determine concentration of small particles near Jupiter	Concentration may increase near a planet; Jovian rings suggested.	to 4 $R_{♃}$	1

EXPERIMENTAL METHODS: ASTEROID BELT AND JUPITER EXPLORATION MISSIONS

Specific techniques and instrumentation that will facilitate the desired scientific observations are listed in the following tables. Where several techniques are available for similar observations, they are listed in order of preference. Also listed are the desired accuracy, the total number of bits of information resulting from a successful experiment and particular advantages and disadvantages of each experiment. The ease of measurement classification takes account of development status of the instruments, weight and power requirements, information retrieval requirements and the limitations imposed on the experiment by the vehicle subsystems (e.g. guidance accuracy and control).

The project priority represents an estimate of the overall priority assigned to the experiment for the purpose of this study. It was formulated on the assumption of a single mission only being available to achieve each overall objective and combines all considerations relating to the probability of extracting useful information from the mission.

EXPERIMENTAL METHODS
ASTEROID BELT

Quantity Measured	Instrument	Range & Accuracy	Total Info. Bits	Advantages (+) Disadvantages (-)	Ease of Meas.	Project Priority
Particle distribution in velocity, size & mass	Thin foil impact detector	Speed - 5 to 12 km/sec $\pm$ 5% Direction - $\pm$ 80° w/resp. to normal $\pm$ 10° Energy - 10^{-10} to 720 joules Mass - 10^{-14} to 10^{-2} gm. Size - 0.25 mm to 5 mm	23/impact	+ Wide range of measurement. Density from size & mass may indicate composition. - Limited area coverage.	2	1
	Microphone gauge	Mass - 10^{-11} to 10^{-5} gm	5/impact	+ Simple, available - Limited area coverage	1	1
	Impact flash detector	Mass - 10^{-14} gm	5/impact	- Requires development. Limited area coverage.	2	3
	Pressure can	Size 10	3/reading	+ Simple, available - Limited area coverage. Limited lifetime	1	3
	Surface erosion meter	Change in surface properties	3/reading	+ Simple, available - Limited area. Limited lifetime & accuracy.	2	3
Particle deflection	Electric/magnetic analyzer	Mass, speed, charge	10/particle	- Requires investigation. Complex.	3	3

EXPERIMENTAL METHODS: ASTEROID BELT (Cont'd.)

Light reflected from particles	Photometer Array	Intensity Polarization	12/particle	+) Simple, light wt. -) Uncertainty in size of particle	2	1
Light reflected from particles at various wavelengths	Laser	Range Radial speed Refl. intensity	15/particles	(+) Size can be estimated from range and brightness (-) Size, weight and power req.	3	3
Radio waves reflected from particles	Radar	Range Radial speed	14/particle	+) Size can be estimated from range & brightness -) Size, weight and power req.	3	2
Composition	Impact mass spectrometer		12/impact	+) Accurate -) Requires investigation	3	1
Composition	Impact optical spectrometer	2000 to 10,000Å 1Å resolution	12/impact	+) Accurate -) Requires investigation	3	2

EXPERIMENTAL METHODS: ASTEROID FLYBY

Quantity Measured	Instrument	Range & Accuracy	Total Info. Bits	Advantages (+) Disadvantages (-)	Ease of Meas.	Project Priority
Surface features, rotation rate and axis.	1. TV camera	1 km resol. 20 pictures	3×10^7	(+) Uses current techniques & equipment (-) Requires pointing of S/C	1	1
	2. Impact probe	1 m. resol. 10 pictures	1.5×10^7	(-) Weight and complexity	3	3
Mass	1. Trajectory perturbation by DSIF	Mass of asteroid greater than 10^{20} kg	0	(+) Simple (-) Limited accuracy. Requires altimeter.	2	1
	2. Auxiliary probe observed from spacecraft	(Dia. > 300 km)	100	(+) Good accuracy (-) Weight & complexity	3	3
Temperature	IR or microwave radiometer	$1-5^{\circ}$ beam 10 scans	4,000	(+) Simple measurement (-) Requires pointing of S/C	1	2
Reflected light and luminescence of surface	Spectrometer/ Polarimeter	$\Delta\lambda \simeq 10Å$	5,400	(+) May give indication of composition	2	2

EXPERIMENTAL METHODS FOR JUPITER FLY-BY

QUANTITY MEASURED	INSTRUMENT	REQUIREMENTS AND ACCURACY	BITS OF INFORMATION COLLECTED	ADVANTAGES (+) DISADVANTAGES (-)	EASE OF MEASUREMENT	PROJECT PRIORITY
Magnetic field intensity on three axes	Flux gate magnetometer - two ranges	Dynamic range $\approx 10^7$, $\pm$ 0.2%	200 x 32	$\ominus$ requires close approach to planet	1	1
Trapped electron fluxes at several energies	Scintillation detectors (low sens.) - geigercounters (high sens.), omni-directional $E > 10$ mev, $E > 100$ kev, $E > 100$ ev; Scintillation detector, - directional $E > 100$ kev	Dynamic range $\approx 10^{10}$, $\pm$ 1%; Dynamic range $\approx 10^7$, $\pm$ 1%	50 x 48	$\ominus$ requires close approach to planet, within $2R_{♃}$	1	1
Trapped proton flux	Scintillation detector, directional $E > 1$ mev	Dynamic range $\approx 10^7$, $\pm$ 1%	50 x 12	$\ominus$ requires close approach to planet	1	1
Infrared spectra of sunlit side	Infrared grating spectrometer, 6000 - 80,000Å, photoresistive detector	$\Delta\lambda \approx 10$Å	1.8×10^5	$\ominus$ heavy	2	1
Infrared spectra in absorption against sun		$\Delta\lambda \approx 10$Å, pointing $\pm 1^\circ$, $\Delta t < 2$ sec	$10 \times 1.8 \times 10^5$	$\oplus$ long optical path for detection of trace constituents	3	1
Ultraviolet spectra of sunlit side	Ultraviolet grating spectrometer, 1000 - 6000Å	$\Delta\lambda \approx 1$Å	1.2×10^5	$\ominus$ heavy, high power consumption	3	2
Ultraviolet spectra in absorption against sun		$\Delta\lambda \approx 1$Å, pointing $\pm 1^\circ$, $\Delta t < 2$ sec	$10 \times 1.2 \times 10^5$	$\oplus$ long optical path for detection of trace constituents	3	2
Intensities of expected ultraviolet lines	Photometer with narrow band interference filters, 10 spectral regions	$\Delta\lambda < 10$Å	10 x 120		2	2
Microwave absorption spectrum	Microwave spectrometer, 0.1 - 2.0 cm	$\Delta\lambda \approx 0.01$ cm	2000	$\ominus$ heavy; high power consumption; requires antenna	2	3
Density, scale height of upper atmosphere	Atmosphere probe with accelerometer	$\Delta t \lesssim 0.001$ sec	1000	$\ominus$ requires ejection of probe at $\approx 20R_{♃}$; burn-up above cloud layers	3	3

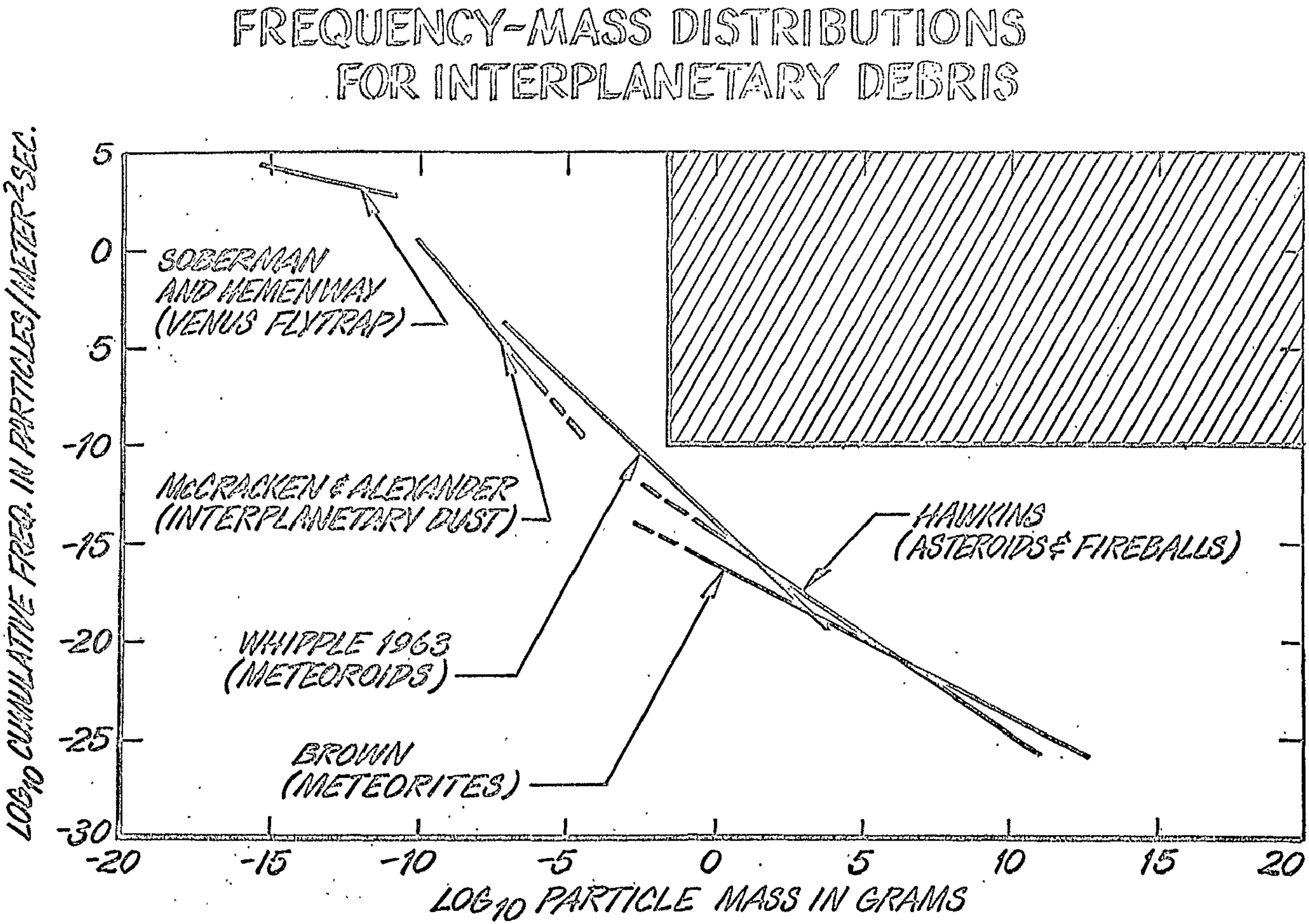
Shape of band as function of height in atmosphere to determine temperature, pressure.	5 fast photometers with narrow band interference filters	$\Delta\lambda \approx 5Å$; pointing $\pm 1^\circ$; $\Delta t < 0.2$ sec	100 x 50	⊖ requires high sensitivity; solar spectrum not well suited as source	3	2
Shape of spectral line or band as function of height in atmosphere, to determine temperature	Fast scanning interferometer directed at sun through atmosphere	$\Delta\lambda \approx 0.01 Å$ over line $1Å$ wide; pointing $\pm 1^\circ$; Δt (one scan) < 0.2 sec	20 x 800	⊖ not developed; rapid scan	3	3
Intensities of raman lines to determine temperature	Excitation of raman lines by laser directed toward Earth	pointing $< \pm 0.1^\circ$; $\Delta t < 1$ sec		⊖ not developed; requires high power	3	3
Fading of sun or star occulted by Jupiter to determine atmosphere scale height	Photometer - telescope with narrow band filters	pointing $< \pm 0.1^\circ$; $\Delta t < 0.2$ sec	50 x 12	⊖ Star tracking may require very high pointing accuracy, more easily done from Earth	3	3
Atmospheric density	Radio occultation of spacecraft		500	⊕ no additional equipment needed ⊖ Composition must be assumed. Frequency limitations	3	2
Direct analysis of constituents	Atmospheric probe with mass spectrometer		1000	⊖ ejection and thermal protection of probe	3	3
Thermal microwave emission from surface and clouds	Microwave radiometer scanning across planet at wavelengths 1.28, 1.35, and 2.0 cm	Beam width $< 5^\circ$; 10 scans	200 x 20	⊖ heavy, requires bulky antenna; 1.28 cm and 1.35 cm lines must be resolved	3	3
Thermal infrared emission from surface and clouds	Infrared radiometer scanning across planet at wavelengths 10, 10.7 micron	Beam width $< 1^\circ$ scan across terminator and red spot, 10 scans	500 x 20		1	1
Infrared pictures of thermal structure of clouds and red spot	5 - 10 micron television camera, moderate resolution	100 line scan	10 x 60000	⊖ requires image converter, not fully developed	3	3
Infrared pictures of thermal structure of clouds and red spot	5 - 10 micron facsimile television	200 line scan	10 x 240000	⊖ not developed	3	3

Far infra red spectrum, thermal radiation balance	Infrared interferometer spectrometer, bolometer detector or filter wedge	5 -100 micron $\Delta\lambda = 1$ micron	4 x 540		2	1
Time sequence pictures of cloud structure, red spot	5° field television camera, high resolution 40° field television camera, high resolution	800 line scan pointing $\pm 5^{\circ}$, red spot 1000 line scan	100 x 3.8×10^{6} 20 x 6×10^{6}	⊖ heavy; high information retrieval ability	2	3
Time sequence pictures of cloud structure, red spot	5°, 40° photographic scanning system	same as above	"	⊖ very heavy, requires radiation shielding, processing on board of photographs ⊕ photographs may be scanned during return voyage	2	3
Surface structure, red spot structure from time delay of reflected radio signal	Radar transmitter-receiver directed at surface	Small beam width pointing $\pm 5^{\circ}$	200 x 400	⊖ high power, large antenna; red spot investigation requires trajectory directly over spot	3	3
Time variation of 18-20 mc radio bursts	Radio receiver continuously monitoring signals at 18, 20 mc	$\Delta t \approx 1$ sec	3×10^{5} x 10	⊕ small size ⊖ requires large information storage capacity	1	1
X-ray emission intensity correlated with radio bursts	Gas-proportional x-ray counters, wide acceptance angle, continuously recording two counters directed toward and away from planet	$\Delta t \approx 1$ sec 2 - 10Å	3×10^{5} x 10	⊖ requires large information storage capacity; may be confused by solar x-rays; present counters have short lives	2	2
Height and electron density of ionosphere layers from critical transmission frequency and time delay of reflected signal	Swept frequency ionospheric sounder transmitting and receiving signals reflected from ionosphere and surface	10 - 500 mc (?) pointing $\pm 5^{\circ}$	10 x 1200	⊕ locates surface ⊖ requires antenna; critical frequencies very uncertain.	1	1
Electron density of ionosphere layers from fading of radio signals transmitted through ionosphere	Telemeter transmitter switched to continuous signal as probe passes behind planet, fading observed on Earth		2 x 500	⊖ Absolute height of layers not known with reference to surface or visible features	3	2

Electron density of ionosphere layers from fading of radio signals transmitted through ionosphere	Fading of transmitter on atmospheric probe entering atmosphere as observed from fly-by probe	$\Delta t \lesssim .001$ sec	1000	? height of layers known only with respect to atmospheric density; probe may burn up before traversal of ionosphere; (conditional to use of probe for density measurement)	3	3
Intensity and location of auroral emissions, especially $H\alpha$ and N_2, N_2^+ and N emissions	Scanning high sensitivity photometers with filters	50 line scan across darkside	10^4 x 48		1	1
Auroral spectra	Fast spectrograph (interferometer?) 3500 - 11000Å	$\Delta\lambda \approx 10$Å	10 x 9000	? requires search for regions of emission	3	2
Night sky spectra			2 x 9000	? not developed, requires advanced optical system for night light collection ability		
Na (D) and N_2 twilight emission intensity	Telescope-photometers scanning across terminator with narrow band filters		80 x 36	? high sensitivity	2	3
$L\alpha$ emission intensity from H around planet	Ultraviolet scanning photometer with narrow band filter at 1216Å.	50 line scan to 10R ♃	10^4 x 12	? Confusion with solar radiation scattered from nearby atoms	3	3
Location of auroral emissions on pictures of dark side	40° low resolution - high sensitivity television with red, blue-violet, $H\alpha$ and perhaps infrared filters	100-200 line scan	20 x 2.4×10^5	? Heavy; image intensifier may be needed	3	3
Location of auroral emissions on pictures of dark side	40° facsimile television with red, blue-violet, $H\alpha$, N_2 band, and infrared filters	100-200 line scan	20 x 2.4×10^5	? heavy	3	3
Light scattering of satellite as function of phase angle, and albedo	Telescope-photometer directed at one satellite	Tracking of satellite $\pm 0.1^\circ$	50 x 12	? Trajectory must not allow Jupiter to enter field of telescope. 2nd midcourse correction reqd. Launch restrictions	2	2
High resolution pictures of satellite	5° high resolution television camera	800 line scan pointing $\pm 1^\circ$	10 x 3.8×10^6	? Trajectory must bring probe very close to satellite	3	2
Infrared spectra of satellite	Infrared grating spectrometer, 6000 - 80000Å	$\Delta\lambda \approx 10$Å pointing $\pm 1^\circ$	6×10^4	? heavy	2	2
Micrometeoroite-dust density near Jupiter	Micrometeorite detector - low sensitivity		50 x 12		1	1

FREQUENCY-MASS DISTRIBUTIONS FOR INTERPLANETARY DEBRIS

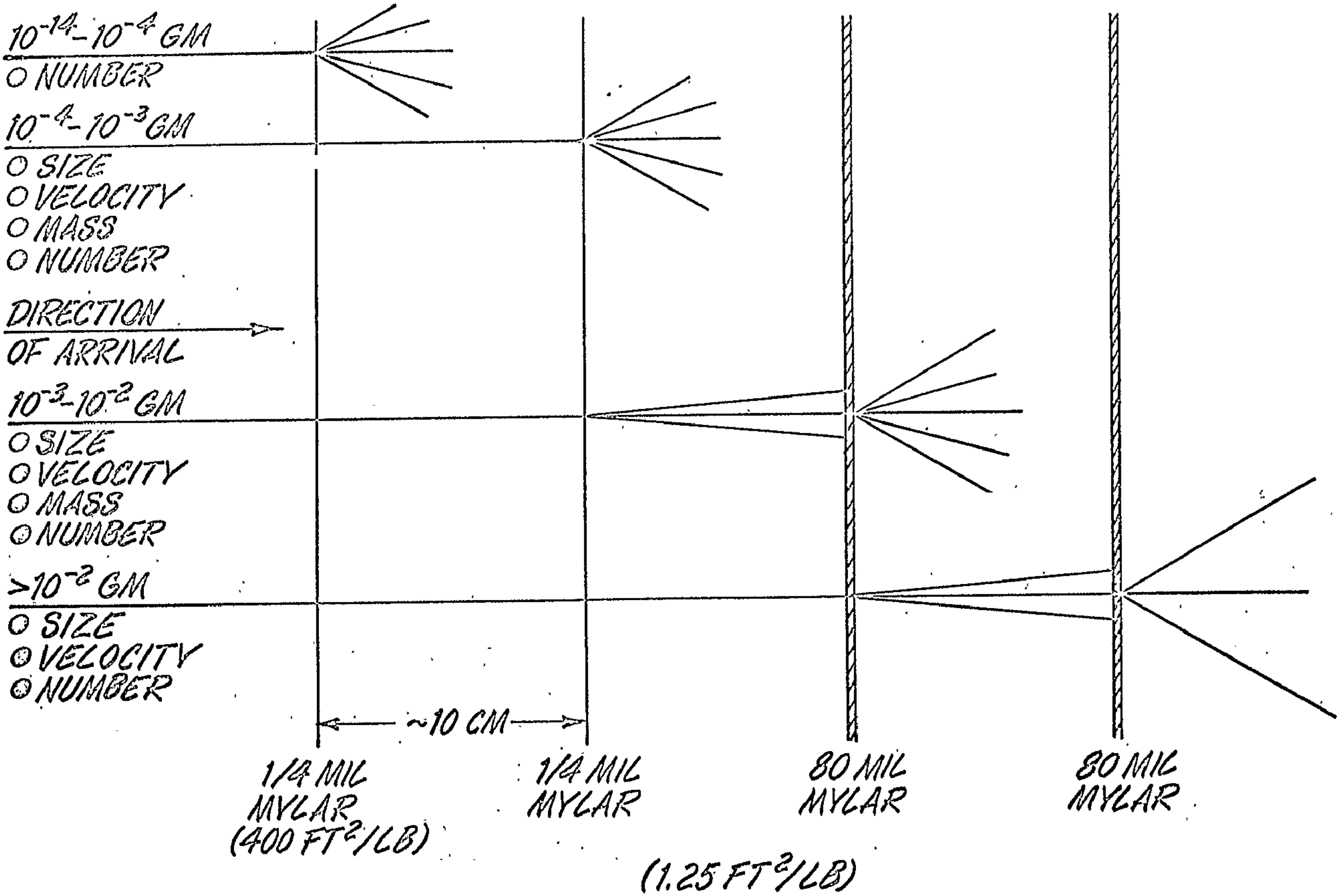
The larger asteroid infrared mass distribution and the observed meteoroid distribution in the vicinity of the Earth contribute to this chart. The ordinate measures the expected impacts per unit area per second of particles greater than a given mass (the abscissa). The shaded area represents the region of concern for structural damage, bounded in mass by the particles that are stopped by the thin-foil impact detector and in frequency of impact by the low probability over the mission duration.


FREQUENCY-MASS DISTRIBUTIONS
FOR INTERPLANETARY DEBRIS
SOBERMAN AND HEMENWAY (VENUS FLYTRAP)
McCRACKEN & ALEXANDER (INTERPLANETARY DUST)
WHIPPLE 1963 (METEOROIDS)
BROWN (METEORITES)
HAWKINS (ASTEROIDS & FIREBALLS)
LOG10 CUMULATIVE FREQ. IN PARTICLES/METER²-SEC.
LOG10 PARTICLE MASS IN GRAMS
5
0
-5
-10
-15
-20
-25
-30
-20
-15
-10
-5
0
5
10
15
20

THIN FILM METEOROID DETECTOR

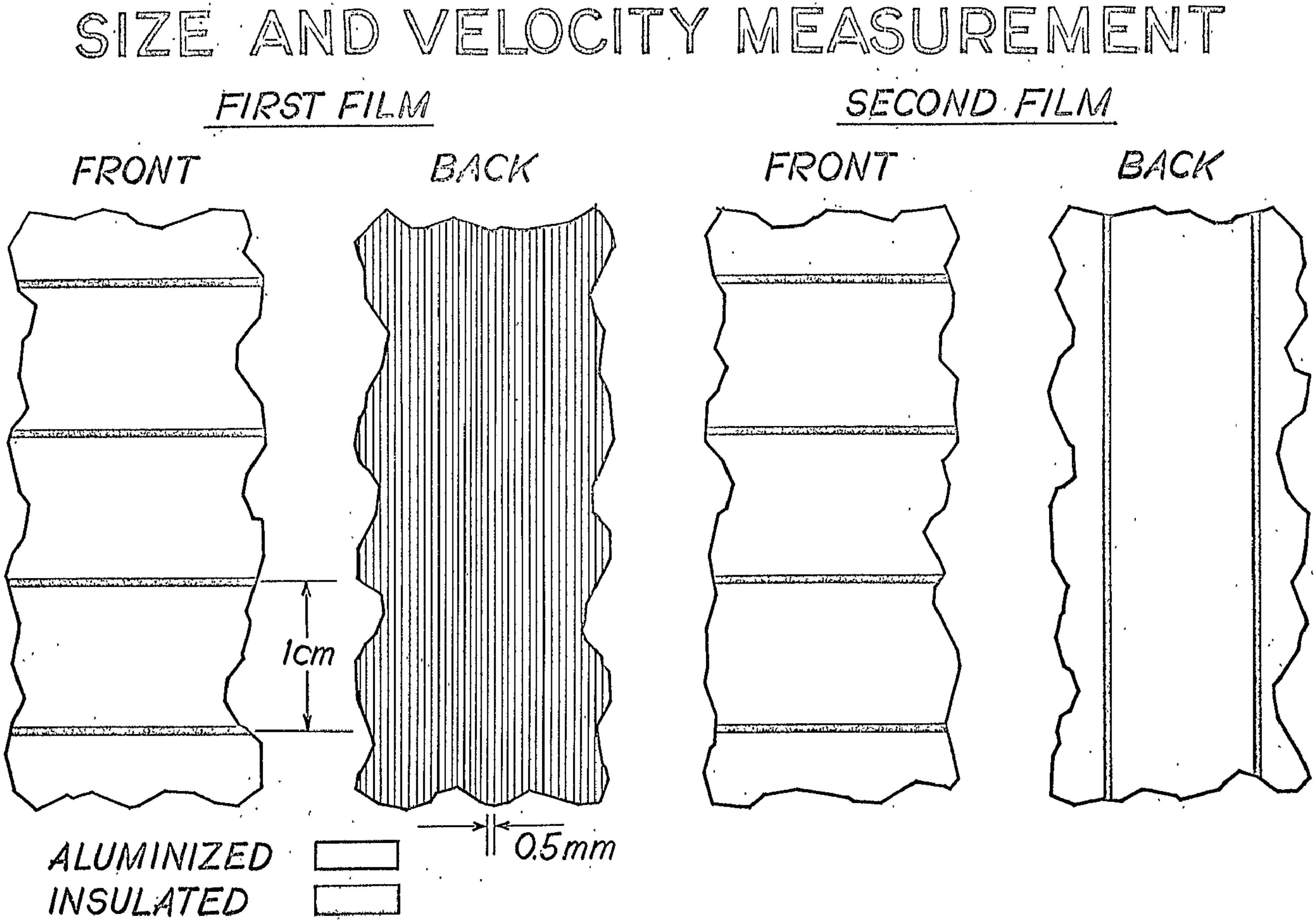
The thin film impact detector consists of multiple spaced films of aluminized polyester of varying thickness. An impact causes an electrical breakdown of potential between the metallic surfaces on each side of the polyester film thus generating an electrical signal. The mass of the particle is proportional to the number of films penetrated. The velocity is determined by the time-of-flight between the first two films.

THIN FILM METEOROID DETECTOR



SIZE AND VELOCITY MEASUREMENT

The particle velocity vector direction of arrival can be determined by measuring the points of impact on the first two films of the thin film meteoroid detector by means of a matrix of metallic bands applied to both sides of the first two films. The fine structure pattern on the back of the first film enables the size of the impacting particle to be measured by the increase in resistance when the fine bands are broken.


SIZE AND VELOCITY MEASUREMENT
FIRST FILM
SECOND FILM
FRONT
BACK
FRONT
BACK
1cm
0.5mm
ALUMINIZED
INSULATED

INTERPLANETARY INSTRUMENTATION

Some instruments concerned with the primary objective of Asteroid/Jupiter missions serve also for interplanetary observations, e.g., magnetic field, micrometeoroid and ionizing radiation detectors. A moderate additional weight of instruments is sufficient to provide comprehensive capability for interplanetary experiments. An interplanetary package of instruments is suggested here that might be expected to go on every deep-space mission of appreciable magnitude. About half the weight of the package consists of instruments (indicated by asterisks) that are part of the primary payload of a Jupiter mission. The remaining instruments are selected to round out the interplanetary aspects of the package while contributing to the capability for determining space environmental conditions near Jupiter.

INTERPLANETARY INSTRUMENTATION

INSTRUMENT	SIZE (in)	WT. (lb)	PWR. (watt)
*Cosmic Dust Detector	5 x 5 x 5	2.5	0.2
*Micrometeoroid Detector	6 x 10 x 10	8	0.5
*Magnetometer	4 x 4 x 6	5	5
*Bi-Static Radar	4 x 4 x 12	5	1.5
Ion Chamber	5 diam.	1.3	0.1
Particle Flux Detector	4 x 5 x 6	2.5	0.35
X-Ray Detector	4 x 5 x 6	5	3
High-Energy Proton Monitor	3 x 4 x 4	4	0.5
Medium-Energy Proton Monitor	4 x 5 x 5	3	1
Low-Energy Plasma Monitor	6 x 8 x 8	7	1.25
Totals	1.1 $ft.^3$	43.3 lb.	13.4 watt

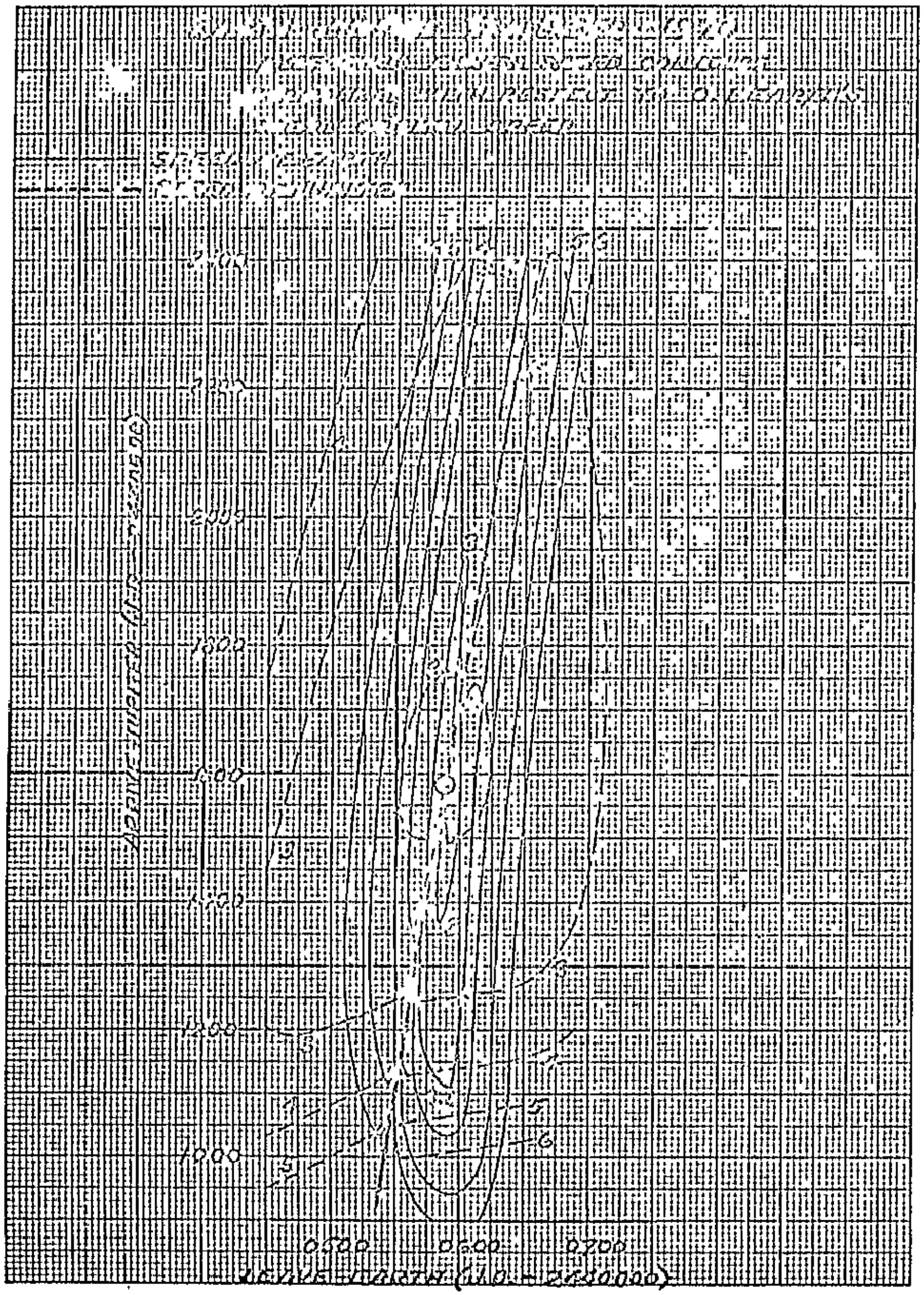
MISSION ANALYSIS

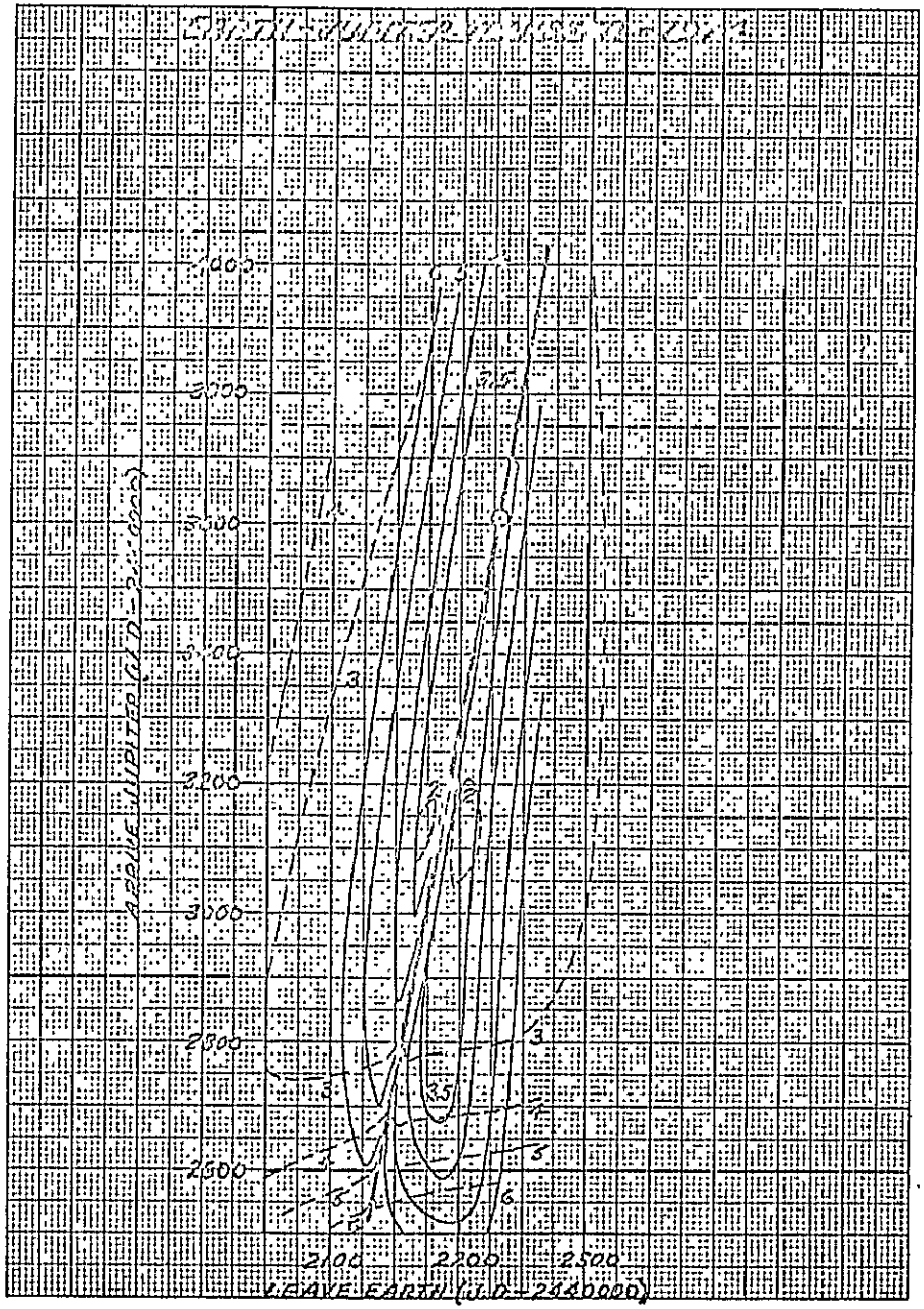
EARTH-JUPITER SPEED CONTOUR CHARTS

These two charts show the hyperbolic excess speeds at Earth departure and at Jupiter arrival for launch periods existing in 1970 and in 1974. As noted, the unit of speed is Earth Mean Orbital Speed (EMOS) of 97,719 ft/sec. The line which runs almost vertically up each chart and separates the speed requirements into two rather distinct regions is the locus of points for which the Earth at departure and Jupiter at arrival are 180 degrees apart in heliocentric longitude. The manner of presentation is identical to that associated with missions to Mars and Venus contained in the NASA Planetary Flight Handbook.

The synodic period between Earth and Jupiter is 399 days. Thus launch opportunities occur about 13 months apart.

The minimum energy velocity requirements show moderate variation from year to year, the minimum departure speed varying from 0.292 EMOS (ΔV = 20,400 ft/sec) in 1970 to 0.321 EMOS (ΔV = 22,200 ft/sec) in 1978. In order to take advantage of the lowest of these velocities, however, trip times of up to 1000 days would be needed.


0500
0600
0700


2100
2200
2300
LEAVE EARTH (J.D.-2440000)

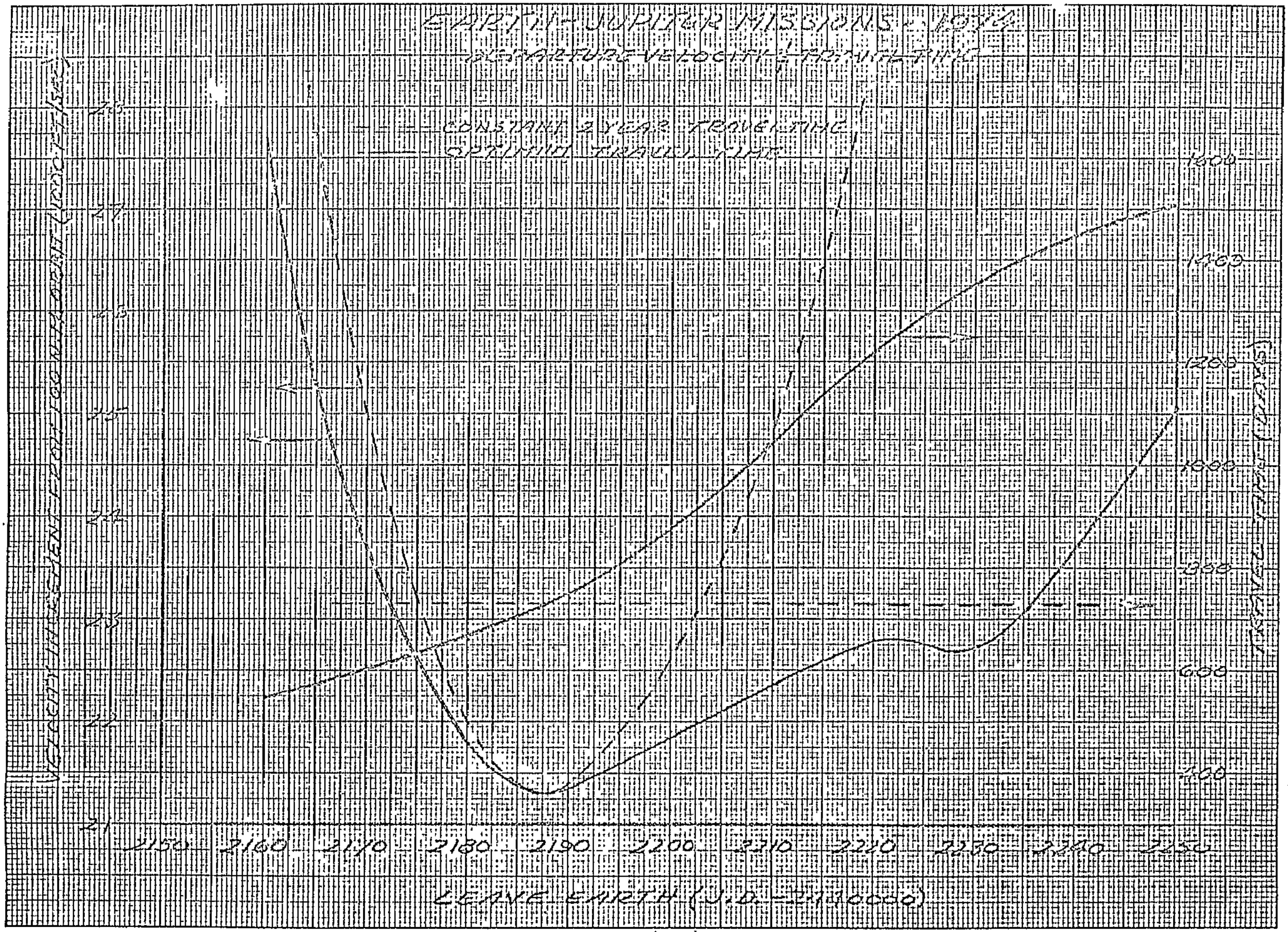
EARTH-JUPITER MISSIONS - DEPARTURE VELOCITY AND TRAVEL TIME

This figure illustrates the strong influence that travel time exerts on Earth departure energy requirements for trips to Jupiter using the 1974 launch period as an example. Two classes of missions are considered. The first, represented by the dashed curves, refers to a constant trip time (assumed in this example to be two years). The second, represented by the solid curves, refers to a situation in which the trip time is chosen so that on any given Earth departure date the departure velocity is minimized.*

Notice first that the minimum departure velocity is 21,300 ft/sec from a 100 nm circular orbit (circular velocity = 25,582 ft/sec). The associated trip time is two years. If the trip time is maintained at two years, it is seen that the velocity increases rapidly both before and after the nominal departure date (J.D. 2442187). If the trip time is allowed to vary, however, the increase in velocity associated with departure delays is much less. The slight decrease in velocity that occurs at about J.D. 2442230 is due to the vehicle arriving at Jupiter near the Earth-Jupiter nodal point.

While a variable trip time is obviously desirable insofar as reducing departure velocity requirements, the large variation (e.g., from 730 days for the minimum energy mission to 1000 days if departure is delayed by 20 days) could cause a large variation in requirements for spacecraft reliability, power supply and communications systems.

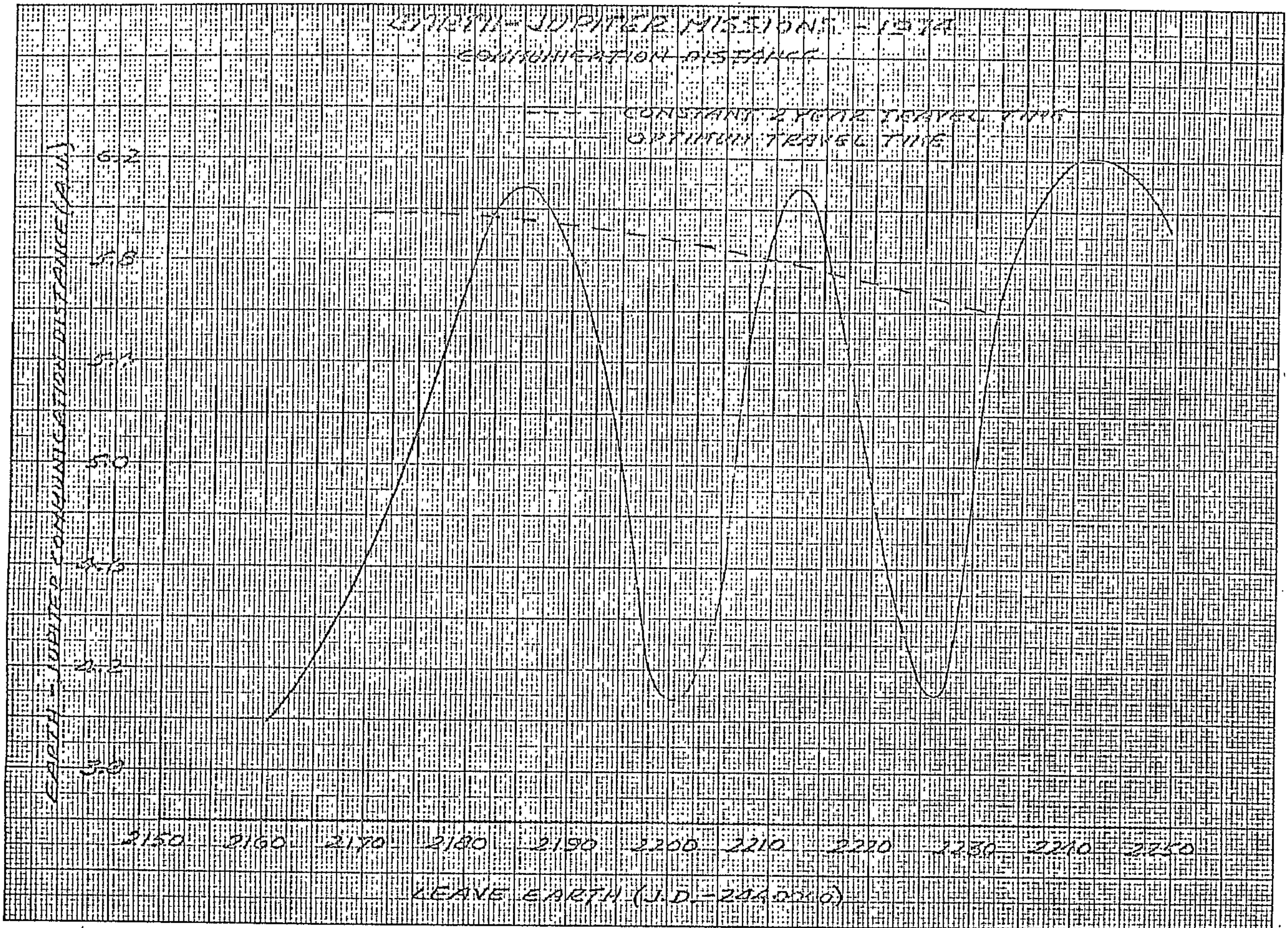
*The data shown here refer only to trajectories of less than 180 degrees. A similar curve could be drawn for the trips of greater than 180 degrees, but the trip times would be considerably longer.



EARTH-JUPITER MISSIONS
DEPARTURE VELOCITY - TRAVEL TIME
CONSTANT 2 YEAR TRAVEL TIME
OPTIMUM TRAVEL TIME
2150
2160
2170
2180
2190
2200
2210
2220
2230
2240
2250
LEAVE EARTH
1600
1400
1200
1000
800
600
400

EARTH-JUPITER MISSIONS - COMMUNICATION DISTANCE

This figure shows the communication distance comparison between the two year missions and the missions which employ the optimum travel times that are shown in the preceding figure. The communication distance requirements associated with the optimized travel times are quasi-periodic with a period of about thirty days measured at Earth departure. This is because, from the preceding figure, the travel time increase during thirty days is slightly longer than one year, causing Earth and Jupiter to nearly repeat their relative positions at arrival. This figure only reflects the Earth-Jupiter communication distance at arrival - not during transit.


EARTH-JUPITER MISSIONS
COMMUNICATION DISTANCE
CONSTANT 2 YEAR TRAVEL TIME
OPTIMUM TRAVEL TIME
EARTH-JUPITER COMMUNICATION DISTANCE (A.U.)
6.2
5.8
5.0
2150
2160
2170
2180
2190
2200
2210
2220
2230
2240
2250
LEAVE EARTH (J.D.-2440000.0)

TYPICAL JUPITER APPROACH HYPERBOLAS

This figure depicts two typical close approach passages of Jupiter. As shown, the pericenter distance is 2 Jupiter radii (1 radius = 44,320 miles). In neither case does a lightside pericenter occur. The pericenter of the dashed trajectory, however, is within 30 deg. of the terminator.

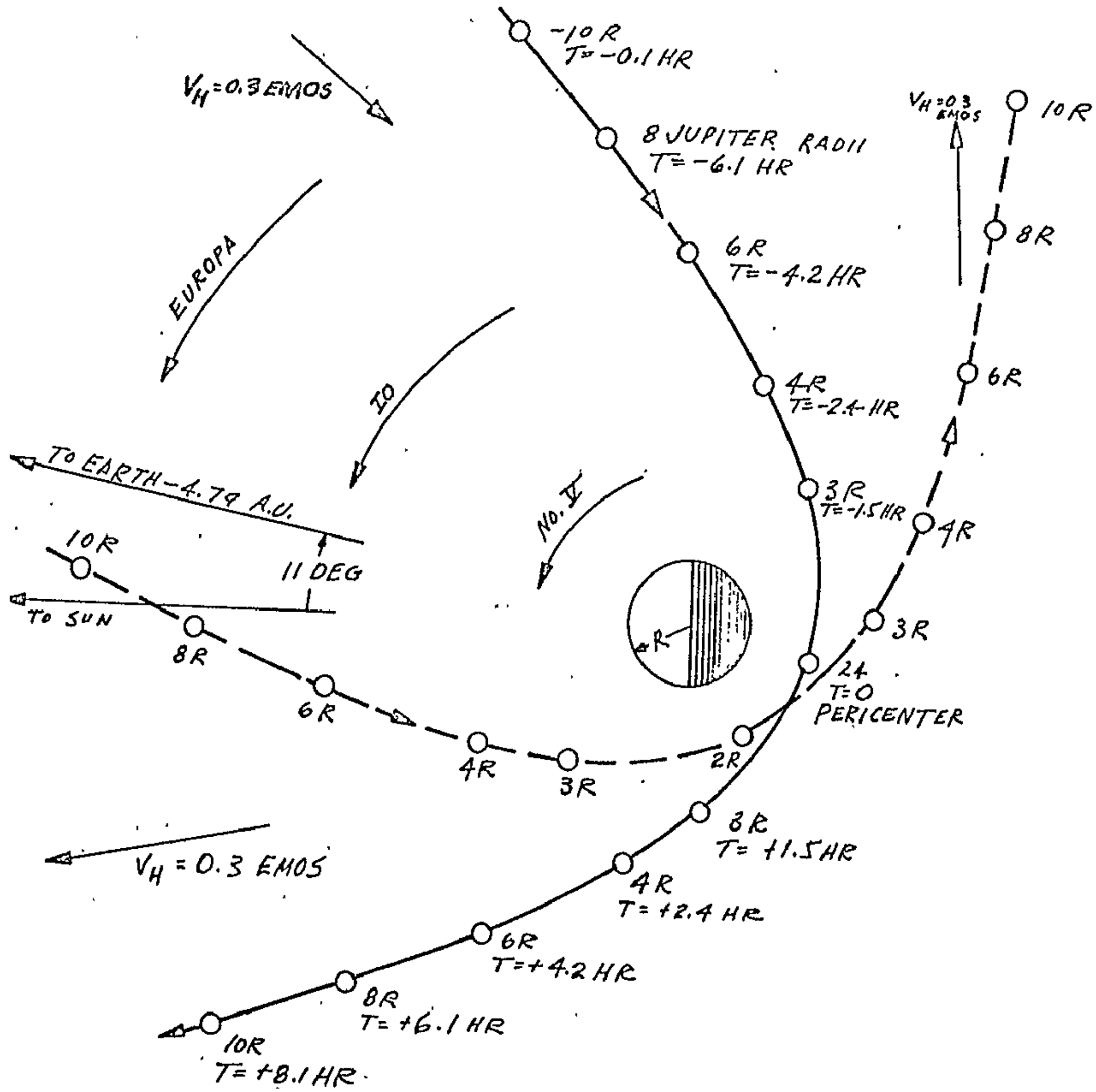
The approach conditions correspond to a representative "fast" trip (610 days) between Earth and Jupiter in 1974. The basic characteristics of this mission are as follows:

	Leave Earth	Arrive Jupiter
Julian Date	2442170	2442780
Speed (EMOS)	0.344	0.300
Right Ascension	341.2	209.6
Declination	-28.6	2.4

By making the appropriate midcourse correction, the approach conditions can be made to yield any inclination relative to Jupiter subject only to the limitation that the inclination be not less than the arrival declination. Since the arrival declination for this trip is only 2.4 degrees, it is apparent that essentially any inclination can be achieved without recourse to a plane change maneuver. The generality of low arrival declinations, and of Earth departure declinations low enough to be compatible with easterly launches from Cape Kennedy, have yet to be determined.

Note that the angle between the Jupiter-Sun line and the Jupiter-Earth line for this particular mission (and all lower energy missions with similar mission times) is 11 degrees. This is the maximum value that this quantity can achieve.

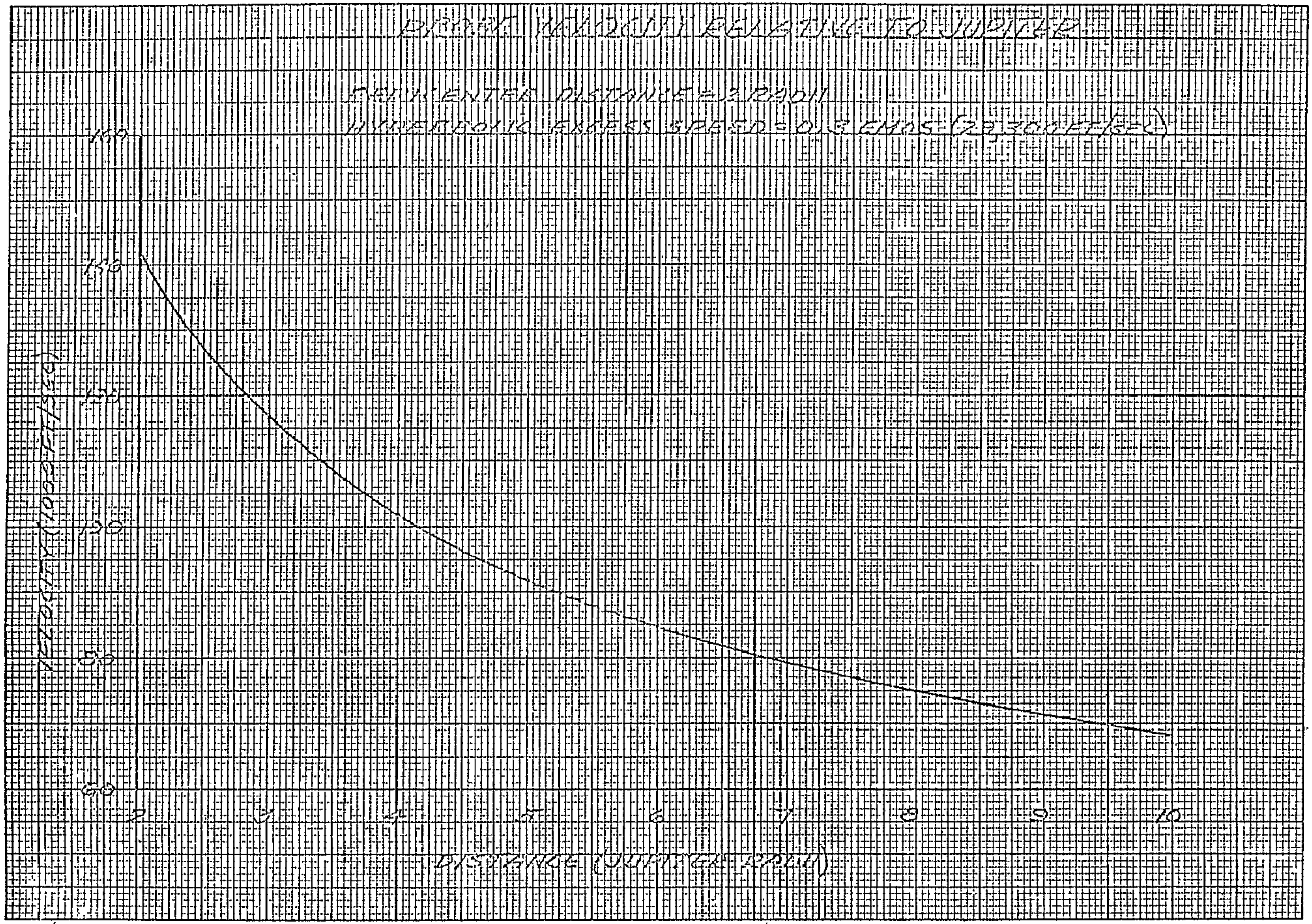
Also shown in the figure are the orbits of the three innermost satellites of Jupiter - No. V, Io, and Europa. Each of these satellites moves in a circular orbit in the plane of Jupiter's equator.



TYPICAL JUPITER APPROACH HYPERBOLAS

PROBE VELOCITY RELATIVE TO JUPITER

This figure shows the velocity profile of the approach hyperbola shown in the preceding figure. Note the high pericenter velocity of over 140,000 ft/sec. Pericenter velocity is influenced almost entirely by pericenter distance. This is because most of the energy of the approach hyperbola is potential energy due to Jupiter's large mass; kinetic energy is only a small portion of the total energy even for the higher energy trajectories being considered.


2
3
4
5
6
7
8
9
10

ASTEROID BELT FLYBY TRAJECTORIES

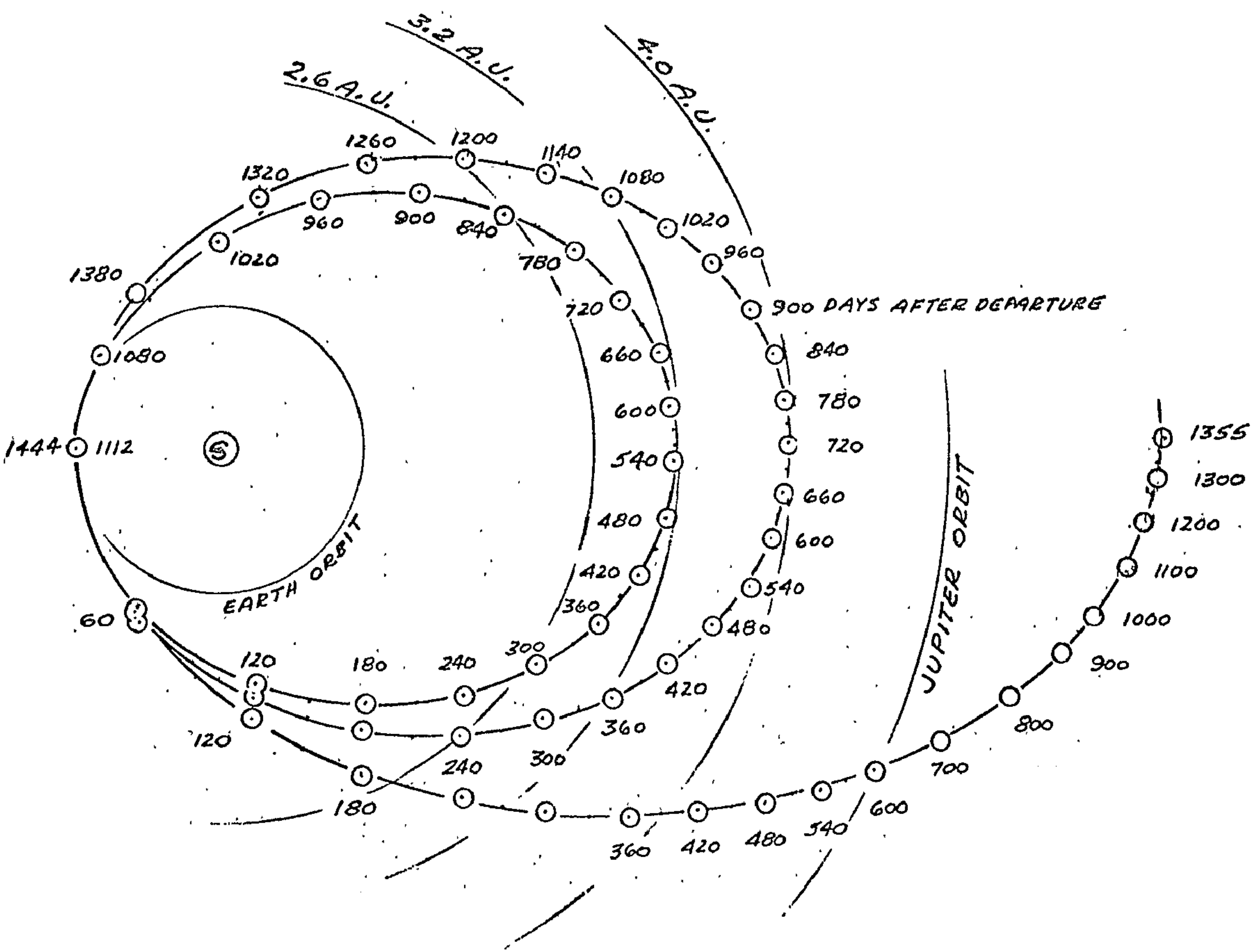
This figure illustrates the heliocentric trajectories of three asteroid belt flyby missions. Two of these have aphelion distances of 3.2 A. U. and 4.0 A. U. The third trajectory shown is typical of a fast trip to Jupiter, arriving at Jupiter's orbit 600 days after Earth departure

The values of 2.6 A. U., 3.2 A. U. and 4.0 A. U. correspond to the outer radii of the three asteroid belts. The following table shows the times spent within the belts for the three trajectories considered. In every case the value quoted is the sum of the outbound and inbound times through the belt.

Time Between Various Radii (Days)

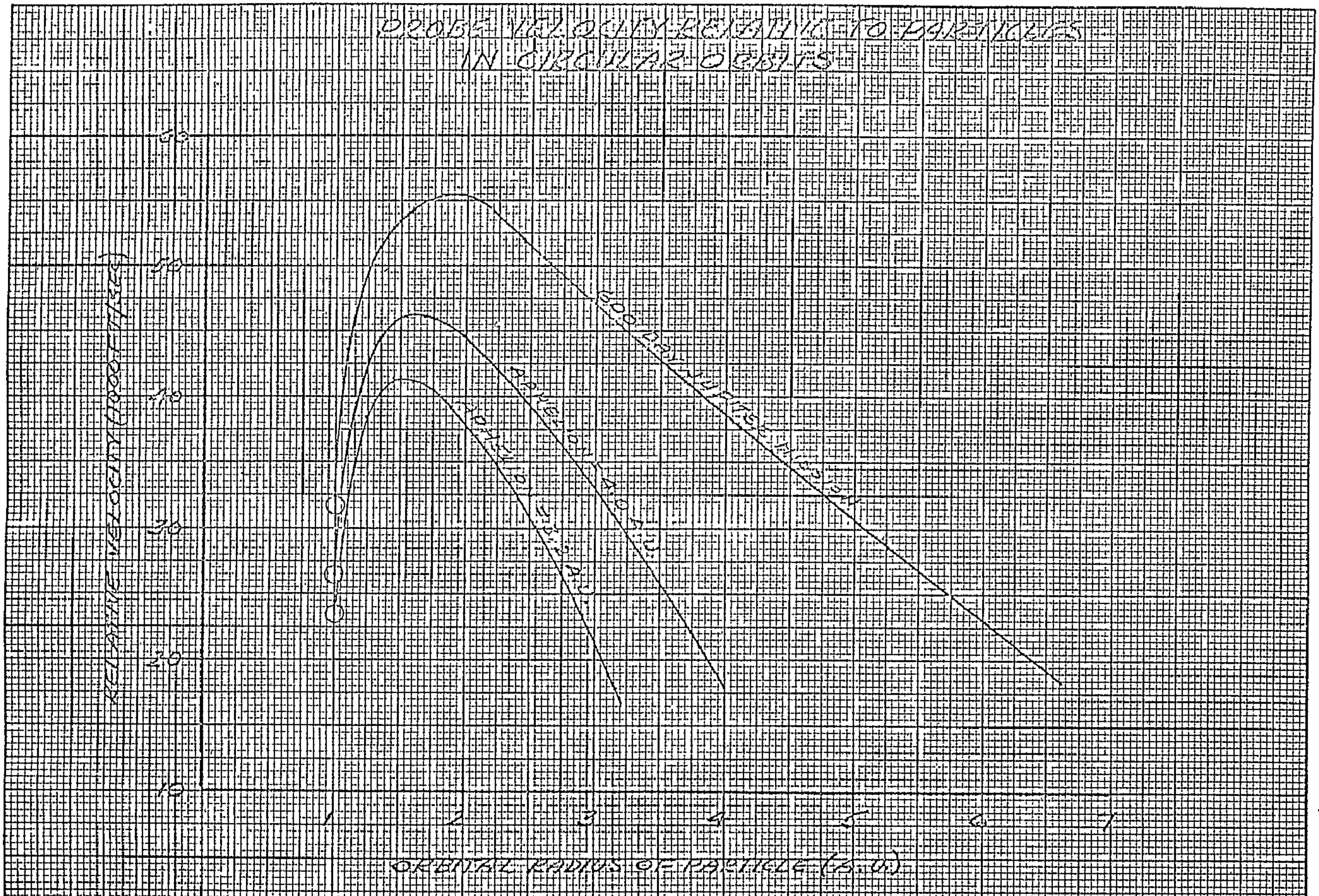
Trajectory	2.0 - 2.6	2.6 - 3.2	2.6 - 4.0	3.2 - 4.0
Aphelion = 3.2 A. U.	220	560	-	-
Aphelion = 4.0 A. U.	160	240	960	730
"Jupiter" Mission	120	150	390	240

ASTEROID BELT FLYBY TRAJECTORIES



ASTEROID BELT FLYBY TRAJECTORIES - RELATIVE VELOCITIES

This figure shows the spacecraft velocity relative to particules moving in circular orbits of various radii. The three cases correspond to those discussed in the previous figure. The three circled points at 1 A.U. are the hyperbolic excess speed requirements at Earth departure.

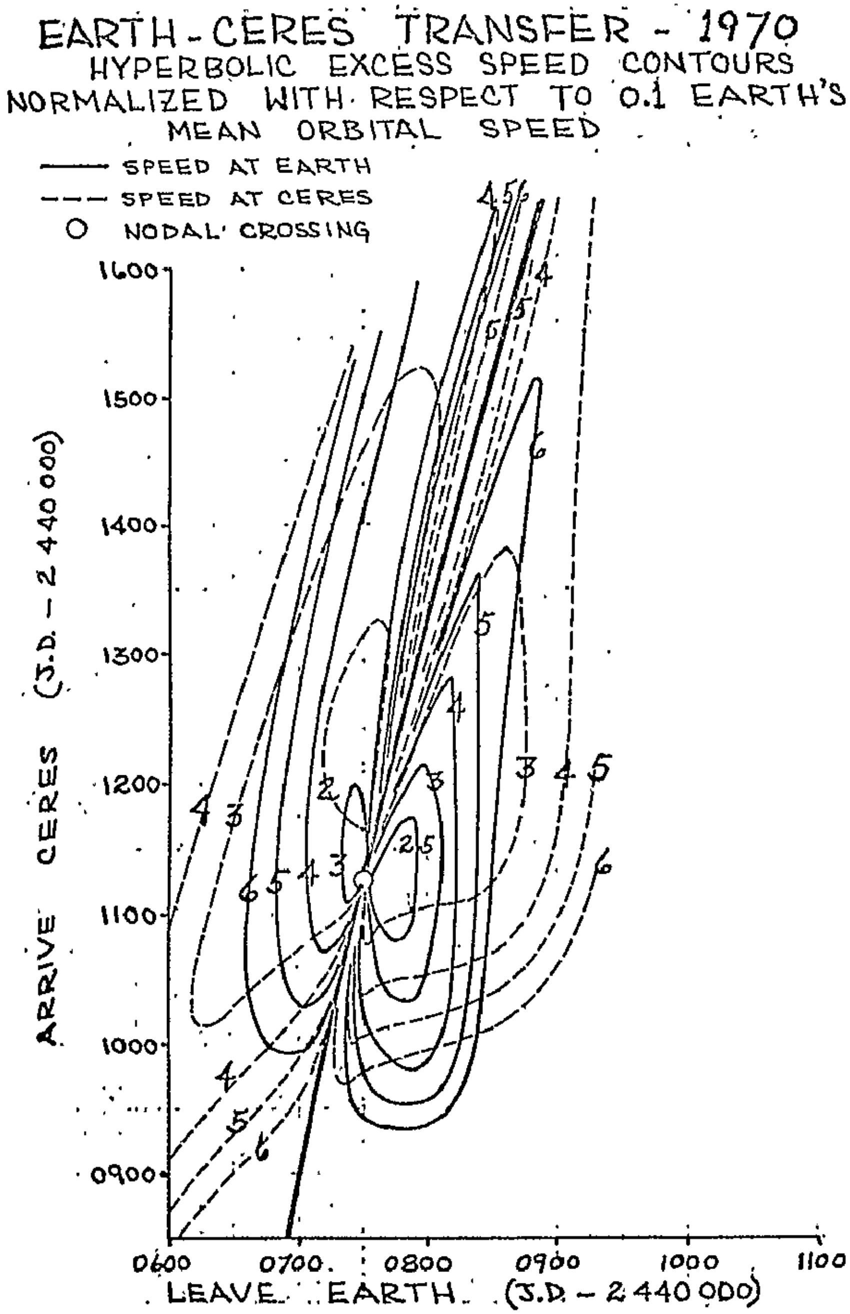

PROBE VELOCITY RELATIVE TO PARTICLES
IN CIRCULAR ORBITS
RELATIVE VELOCITY
ORBITAL RADIUS OF PARTICLE (A.U.)
10
20
30
40
50
1
2
3
4
5
6
7
4.0 A.U.
3.2 A.U.

EARTH-CERES SPEED CONTOUR CHARTS

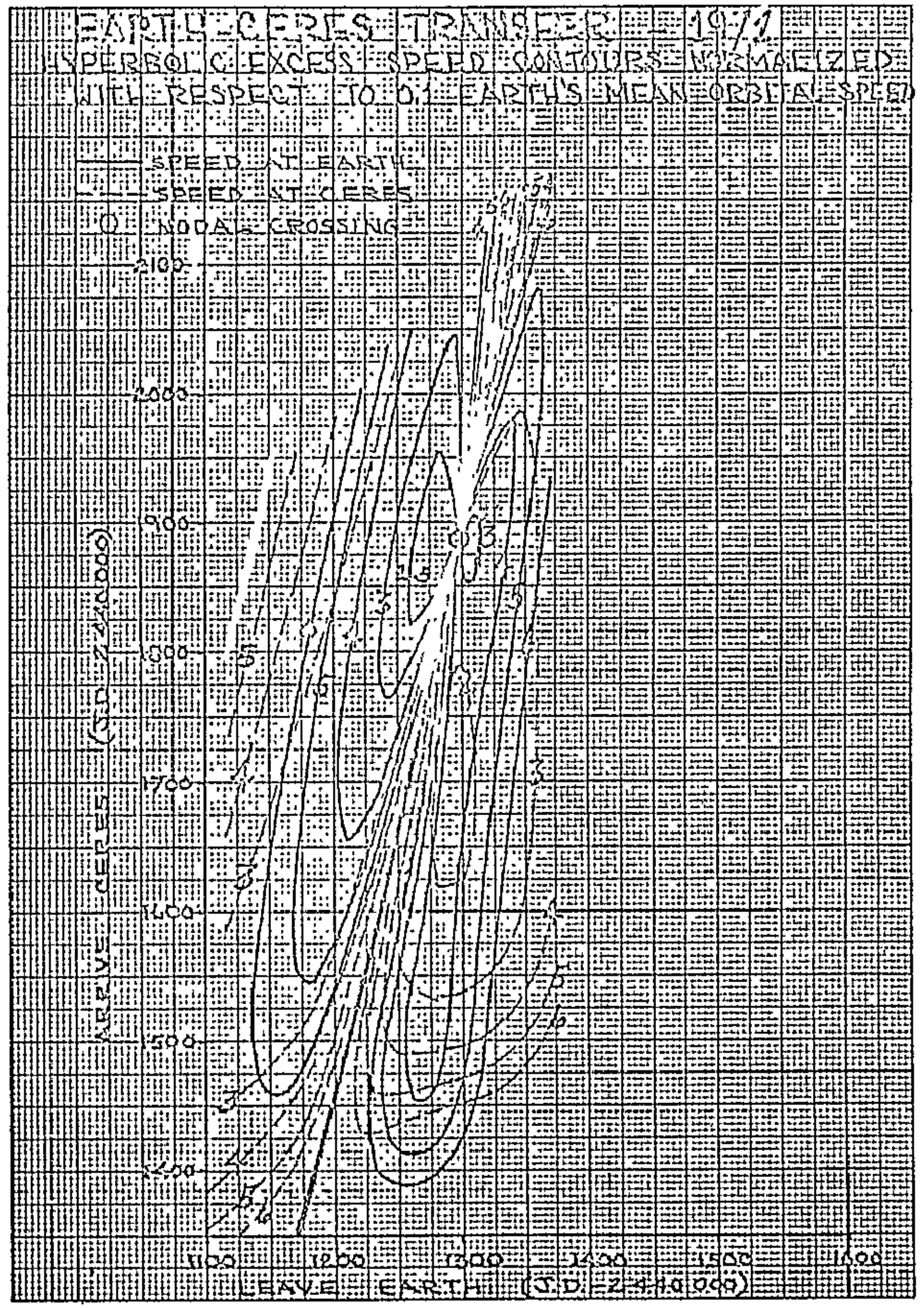
Energy and trip time requirements for trips to particular asteroids will show more variation betwen successive launch opportunities than for trips to Jupiter. This is because of the higher eccentricities (0.089 for Vesta, 0.076 for Ceres) and higher orbit inclinations (7.13 deg. for Vesta, 10.61 deg. for Ceres). Corresponding values for Jupiter are 0.048 and 1.31 deg.

Although complete trajectory data to the asteroids is not yet available the requirements shown here for trips to Ceres in 1970 and 1971, bear out the expected variation. In 1970 the nodal crossing occurs about eighty days before a vehicle launched on a "Hohmann" transfer would arrive. The minimum departure speed, which occurs near the nodal crossing, is 0.221 EMOS.* The corresponding travel time is 360 days. In 1971, however, the nodal crossing occurs about 110 days after a vehicle launched on a "Hohmann" transfer would arrive. Thus, the low energy transfers to Ceres in 1971 will require about 570 days. Further illustrating the contrast, a 360-day trip in 1971 would require an Earth departure speed of 0.38 EMOS. This is an increase in ΔV of 9600 ft/sec compared to a 360-day trip in 1970.

*Hohmann departure speed = 0.21 EMOS.



EARTH-CERES TRANSFER - 1970
HYPERBOLIC EXCESS SPEED CONTOURS
NORMALIZED WITH RESPECT TO 0.1 EARTH'S
MEAN ORBITAL SPEED
SPEED AT EARTH
SPEED AT CERES
NODAL CROSSING
ARRIVE CERES (J.D. – 2 440 000)
LEAVE EARTH (J.D. – 2 440 000)



EARTH-CERES TRANSFER - 1971
HYPERBOLIC EXCESS SPEED CONTOURS NORMALIZED
WITH RESPECT TO 0.1 EARTH'S MEAN ORBITAL SPEED
SPEED AT EARTH
SPEED AT CERES
NODAL CROSSING
ARRIVE CERES (J.D. – 2 440 000)
LEAVE EARTH (J.D. – 2 440 000)

TYPICAL CERES APPROACH HYPERBOLAS

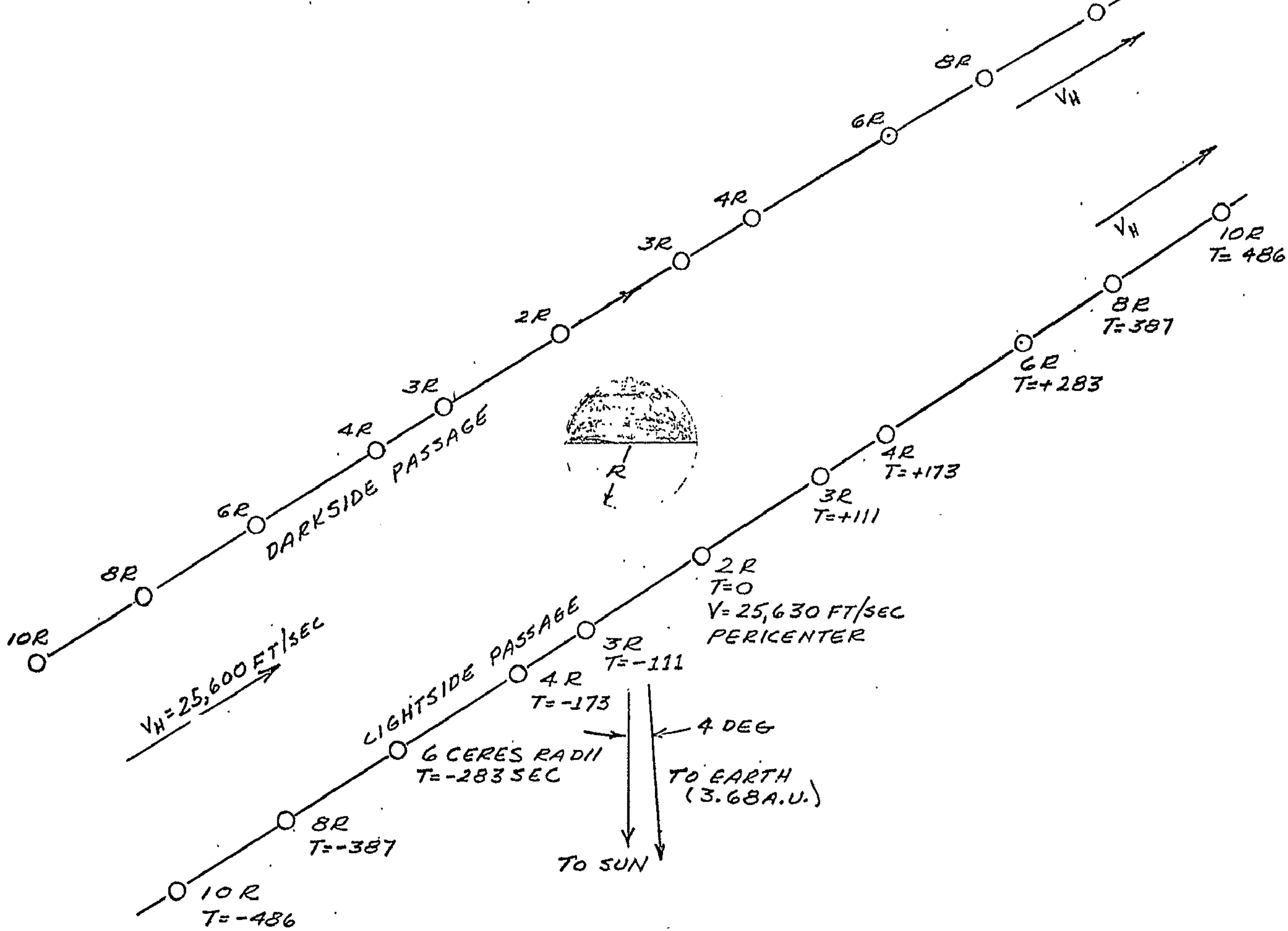
As observed from the figure the hyperbolas relative to Ceres (and, therefore, hyperbolas relative to the less massive asteroids) degenerate to essentially straight lines, the asymptote bend angle being only 1.2 deg. for the trajectory shown.

The time spent near Ceres is short, requiring only 486 sec. to approach from 10 radii to pericenter (assumed, in this instance, to be 2 radii). The variation in velocity along the trajectory is small. The increase of 30 ft./sec. from the hyperbolic excess velocity to pericenter velocity, however, could be detected by vehicle-borne sensors as an aid to refining the mass estimate of Ceres.* The perturbation on the spacecraft motion by Ceres will cause the heliocentric velocity and path angle before and after passage to differ by about 20 ft./sec. and 0.7 deg, respectively.

The approach conditions are based on the minimum departure velocity mission of 1970. Earth departure speed is 0.221 EMOS (ΔV = 16,600 ft./sec.). Transit time to Ceres is 360 days.

*In this example the mass of Ceres is assumed to be 1/8000 of the Earth's mass.

TYPICAL CERES APPROACH HYPERBOLAS



SUBSYSTEMS

SUBSYSTEM DIAGRAM

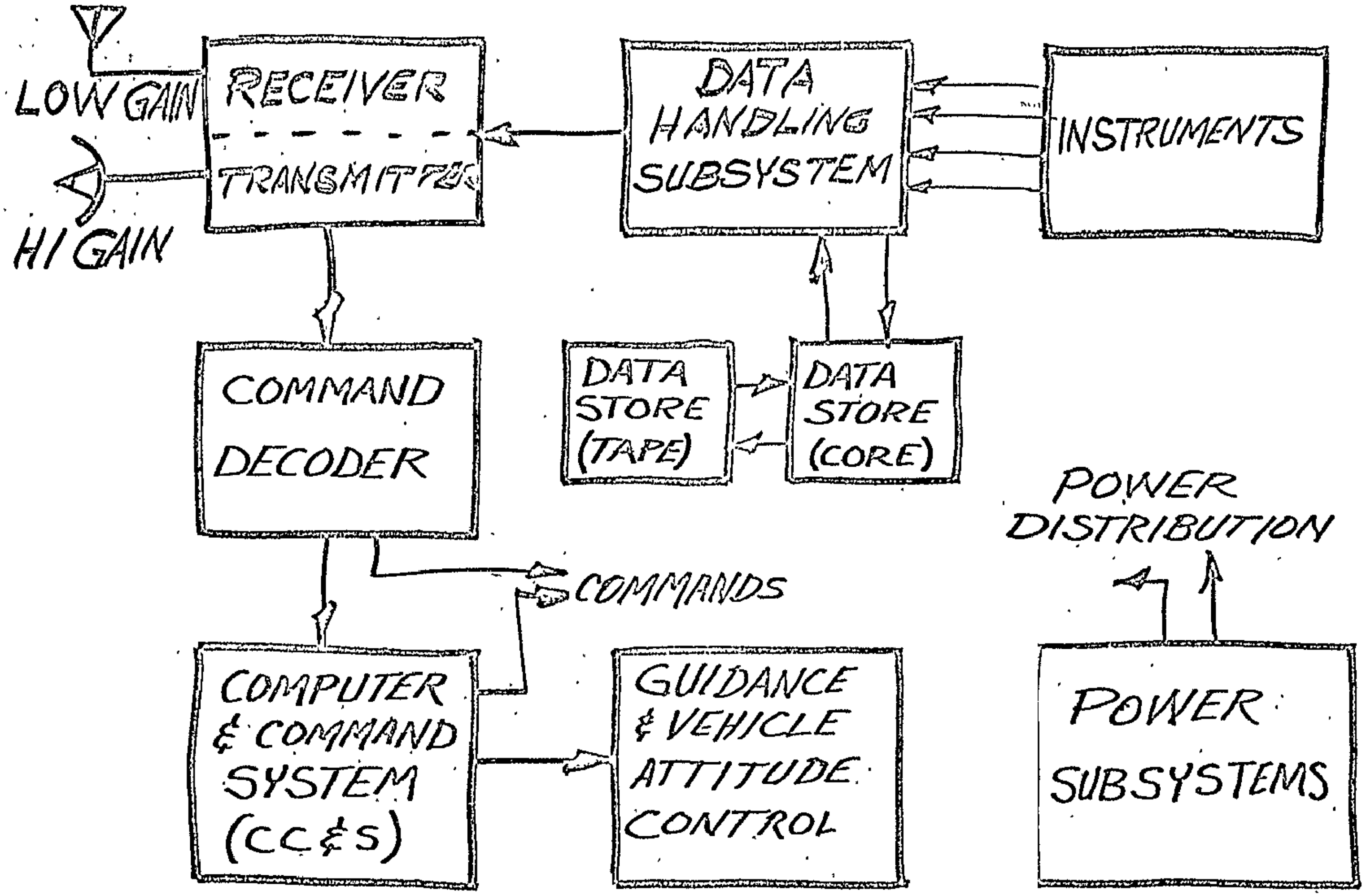
Basically, the vehicle subsystems are similar to those used in previous space missions. The utilization of the component parts is rearranged to suit the specific operational requirements. The major differences for each of the missions - asteroid belt, asteroid inspection, or Jupiter flyby are in the data handling sequences, the instrumentation compliment, and the power utilization. The requirements for the three basic missions are as follows:

Asteroid Belt, data acquisition is accomplished over a period of one to three years at relative low data rates.

Asteroid Inspection, the asteroid experiments must be performed in a relative short interval (4 to 5 hours).

Jupiter flyby, similar to the asteroid inspection mission except the period of encounter is several days with an increased data acquisition rate.

SUBSYSTEMS DIAGRAM



COMMUNICATIONS SENSITIVITIES

A model of the communication subsystem has been extrapolated from the basic Mariner concept. For this model, a 7-foot parabolic antenna and 10-watt transmitter has been selected. Examination of the effect of Jupiter's radio noise (assumed 2000°K at 2.2 KMC) has been made for the available data transmission rate at a 10^{-3} bit error rate for distances of 4.0, 4.8, 5.0, and 6 AU. The data rate has been calculated for a 20-watt and 70-watt transmitter at a nominal range of 4.8 AU. The time required to transmit five million bits of data at 4.8 AU is indicated for each of the above systems plus the time required at 33-1/3 and 8-1/3 bits per second. Five million bits represents the nominal storage capacity of the magnetic tape system used on the Mariner C system.

Additional bit rate calculations are shown for the command link utilizing either the omnidirectional or the high gain antenna.

Also included on the chart are the signal transit times at the various ranges expected on the Jupiter flyby mission. These transit times seriously affect the operational sequences for the spacecraft and DSIF since a minimum of two transit periods are required to insure coherent communications.

COMMUNICATIONS SENSITIVITIES

FUNCTION	CONDITIONS	EARTH-JUPITER RANGE 4.0 AU	4.8 AU	5.0 AU	6.0 AU	TRANS. TIME FOR 5×10^6 BITS HOURS
DATA RATE bit error rate 10^{-3}	a- 10 W XMTR. 7' PARABOLA	144	102	93	65	13.6
	b- JUPITER RADIO NOISE 2000°K ≡ 1.5 db AT 4 AU	102	72	66	45	19.3
	c- 20W XMTR. INCL. (b)		144			9.7
	d- 70W XMTR. INCL. (b)		512			2.7
	e- 33 1/3 BITS/SEC					41.8
	f- 8 1/3 BITS/SEC					167.0
COMMAND RATE bit error rate 10^{-6}	a- OMNI ANTENNA 0 db		3.38			1 BIT PER SEC. REQ.
	b- 7' PARABOLA 30 db		3,380			
		UNITS = BITS/SEC				
SIGNAL TRANSIT TIME (1 WAY)	$T = 8.3$ MINUTES/AU $1 \text{ AU} = 150 \times 10^9$ METERS $C = 3 \times 10^8$ METER/SEC	MINUTES				
		33.2	39.9	41.5	49.8	

GUIDANCE AND CONTROL CONCEPTS

Determination of the vehicle's position entirely by DSIF tracking will provide adequate accuracy for all experiments. Either two-way doppler or range tracking may be used. The possibility of using on-board optical equipment which tracks an asteroid as an aid to guidance is being studied. For an asteroid fly-by a correction shortly after launch and another several days before encounter will be required. For the Jupiter fly-by the first correction gives sufficient accuracy for the experiments so far considered.

A continuously operating attitude control system has been considered. The weight required to implement such a system appears reasonable. The major problem area is concerned with the reliability that may be expected during operation for 600 days or longer.

GUIDANCE AND CONTROL CONCEPTS

GUIDANCE

- DSIF TRACKING
- VELOCITY ERROR ~ .03 m/SEC
- MANEUVER EXECUTION ERROR ~ 0.7 m/SEC
- RMS MISS AT JUPITER WITH ONE CORRECTION ~ 2000 KM
- RMS MISS AT ASTEROID WITH TWO CORRECTIONS ~ 350 KM

ATTITUDE CONTROL

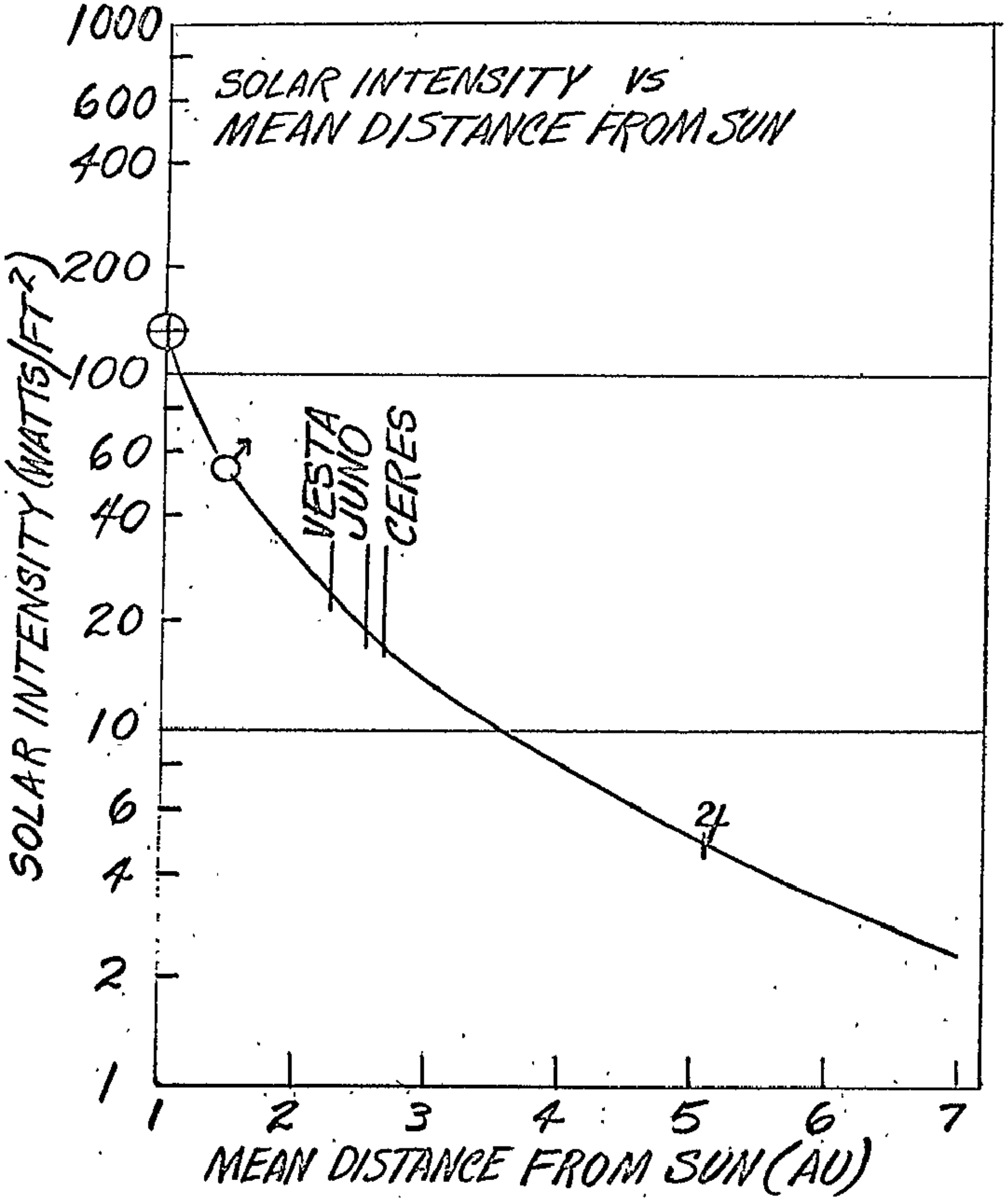
- SUN REFERENCED PITCH AND YAW STABILIZATION
- CANOPUS REFERENCED ROLL STABILIZATION
- DERIVED RATE INCREMENT DAMPING
- 2000 SECOND LIMIT CYCLE
- IMPULSE EXPENDITURE ~ 30 $\frac{\#\text{-SEC}}{\text{MO.}}$

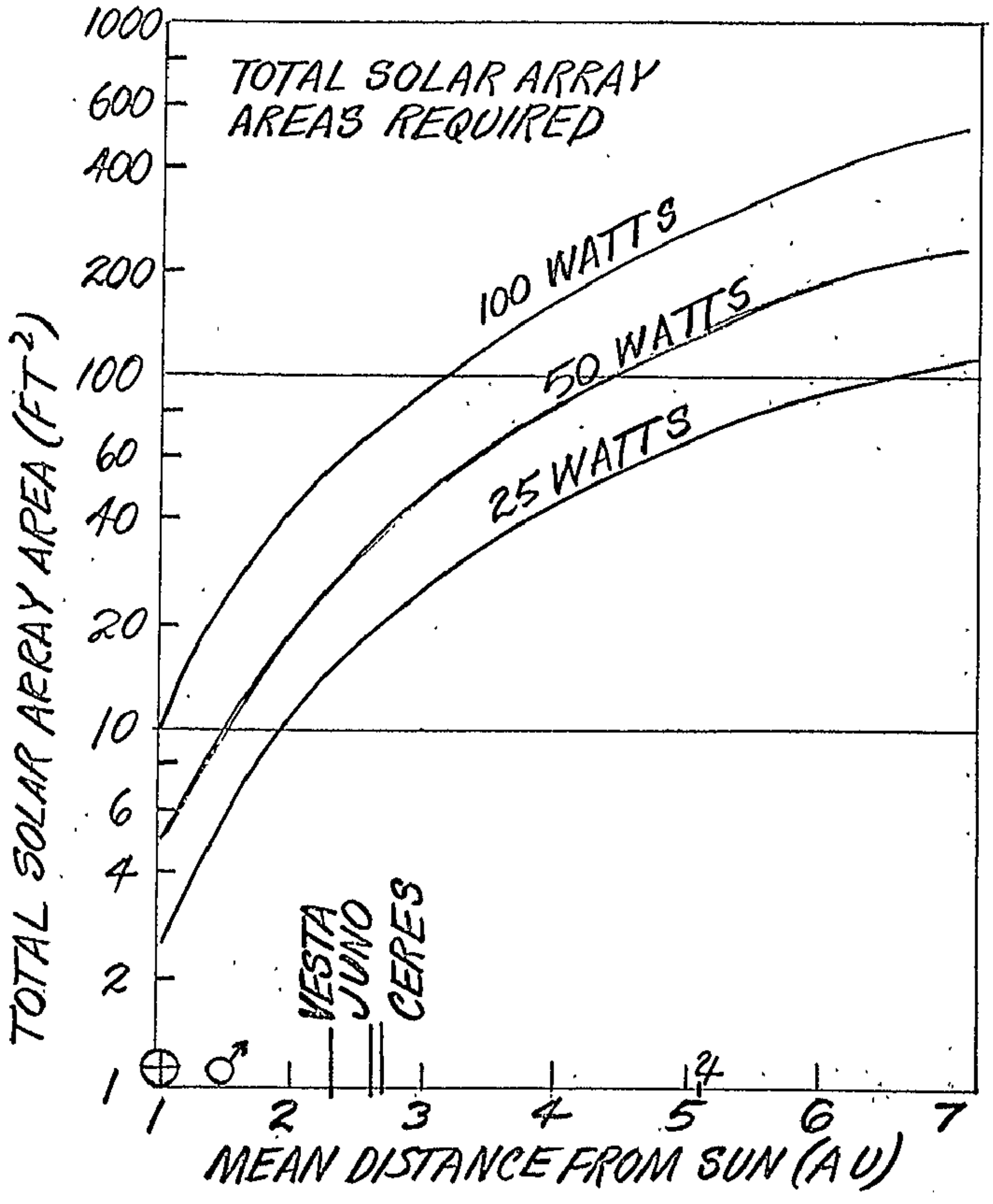
SOLAR POWER REQUIREMENTS

These two figures show the operating capabilities of solar panels. Panel area and solar intensity as a function of distance from the sun are given. The use of solar panels as a primary power source for the Asteroid Belt or Asteroid Flyby missions appears feasible at continuous power output levels of 100 watts. For these applications the solar array area would be approximately 200 square feet (including a 100% contingency for normal degradation effects) at a weight of 350 to 400 pounds. Secondary batteries would provide peak power requirements for maneuvers and communications at levels of 200 watts for periods of 3 to 4 hours at each contact.

The use of solar panels for the Asteroid missions is not recommended, however, because of panel degradation (due to asteroidal particles) resulting in a power output below the minimum required for the mission. The required solar arrays (for all missions) result in a greater weight penalty than that imposed by Radioisotope Thermoelectric Generators (RTG).

SOLAR POWER REQUIREMENTS

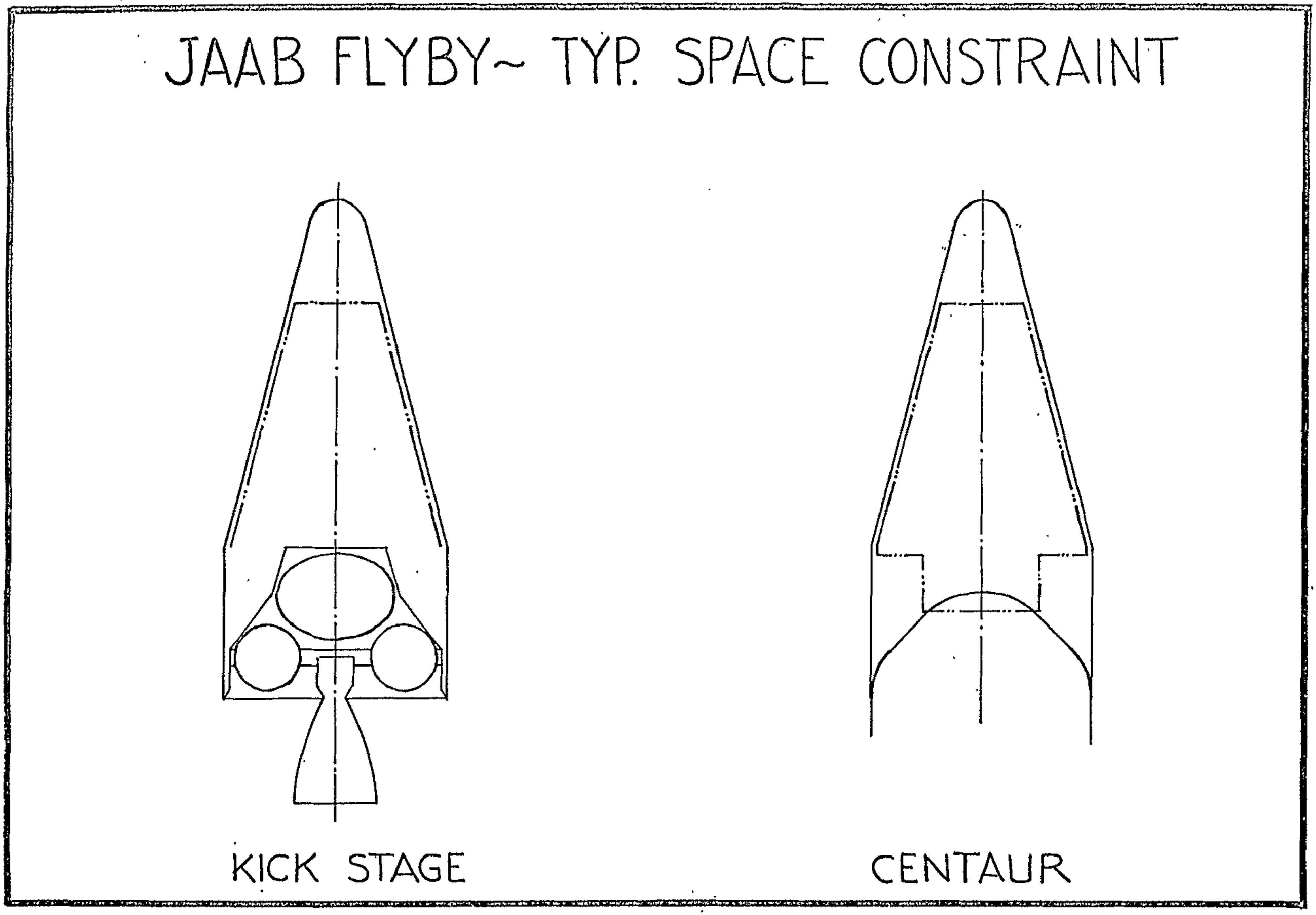




VEHICLE DESIGN

TYPICAL PAYLOAD SPACE CONSTRAINT

All the potential booster arrangements investigated have either a Centaur or a small high energy kick stage as the final propulsion unit. This figure shows typical spacecraft volumes available with a Surveyor type shroud. The configuration using a Centaur final stage defines the least available volume and this criterion was used for all spacecraft concepts.


JAAB FLYBY~ TYP. SPACE CONSTRAINT
KICK STAGE
CENTAUR

TYPICAL CONCEPT WEIGHTS

Weights for four concepts are shown. The Jupiter mission versions differ primarily in their structural configuration because of different arrangements of the scientific instruments.

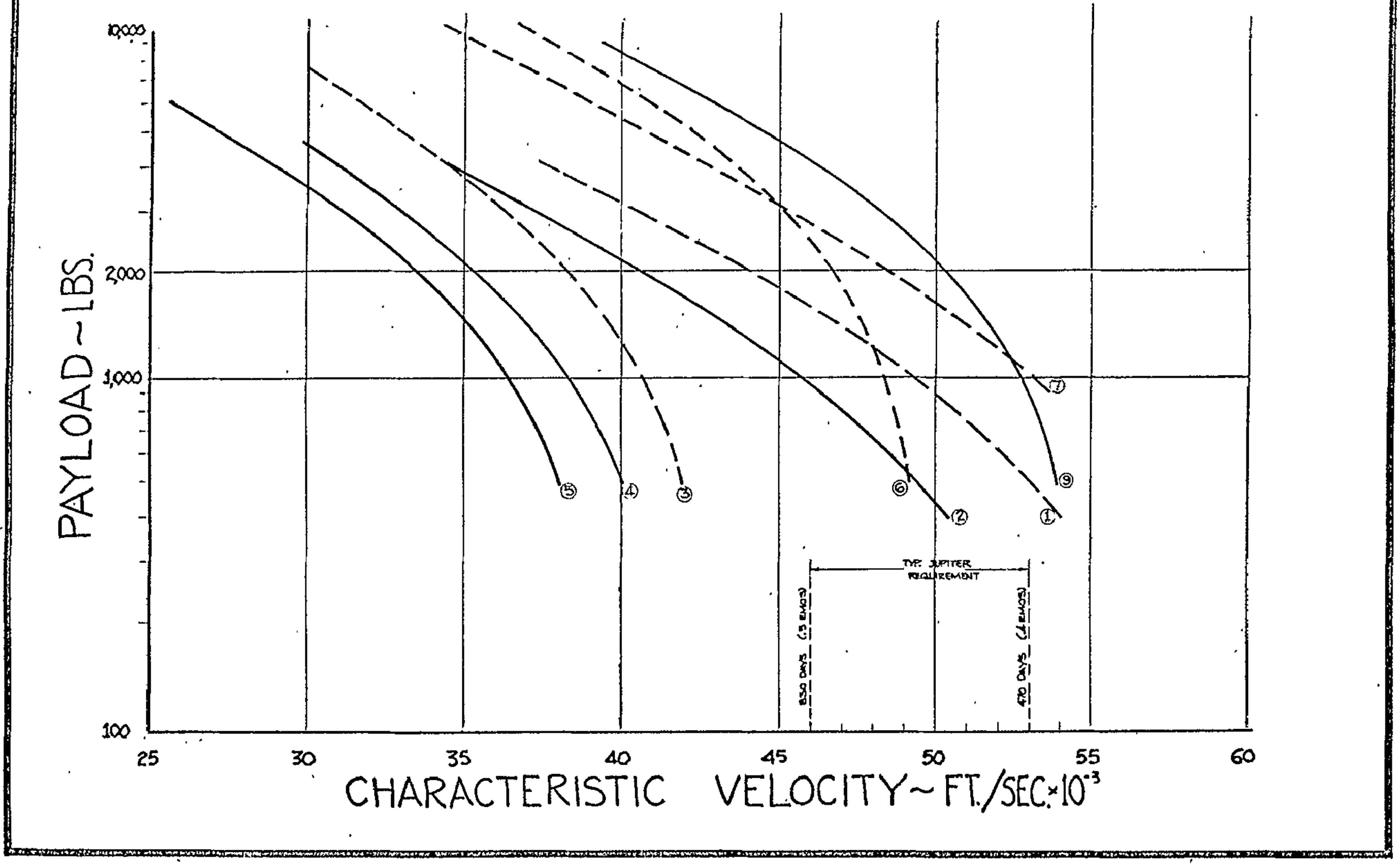
JAAB FLYBY~TYP. CONCEPT WEIGHTS

	JUPITER FLYBY-1	JUPITFR FLYBY-2	ASTEROID FLYBY	ASTEROID BELT FLYBY
STRUCTURE	215.5	253.0	196.5	239.5
COMM. & DATA HAND.	227.0	227.0	227.0	227.0
GUID. & CONTROL	163.0	163.0	163.0	163.0
POWER SYSTEM	185.0	185.0	185.0	185.0
PROPULSION	105.0	105.0	105.0	0
SCIENTIFIC EQUIP.	331.0	331.0	175.5	256.0
THERMAL & CONT.	113.0	95.0	95.0	95.0
TOTAL WEIGHT	1339.5	1359.0	1147.0	1165.5

BOOSTER CAPABILITY

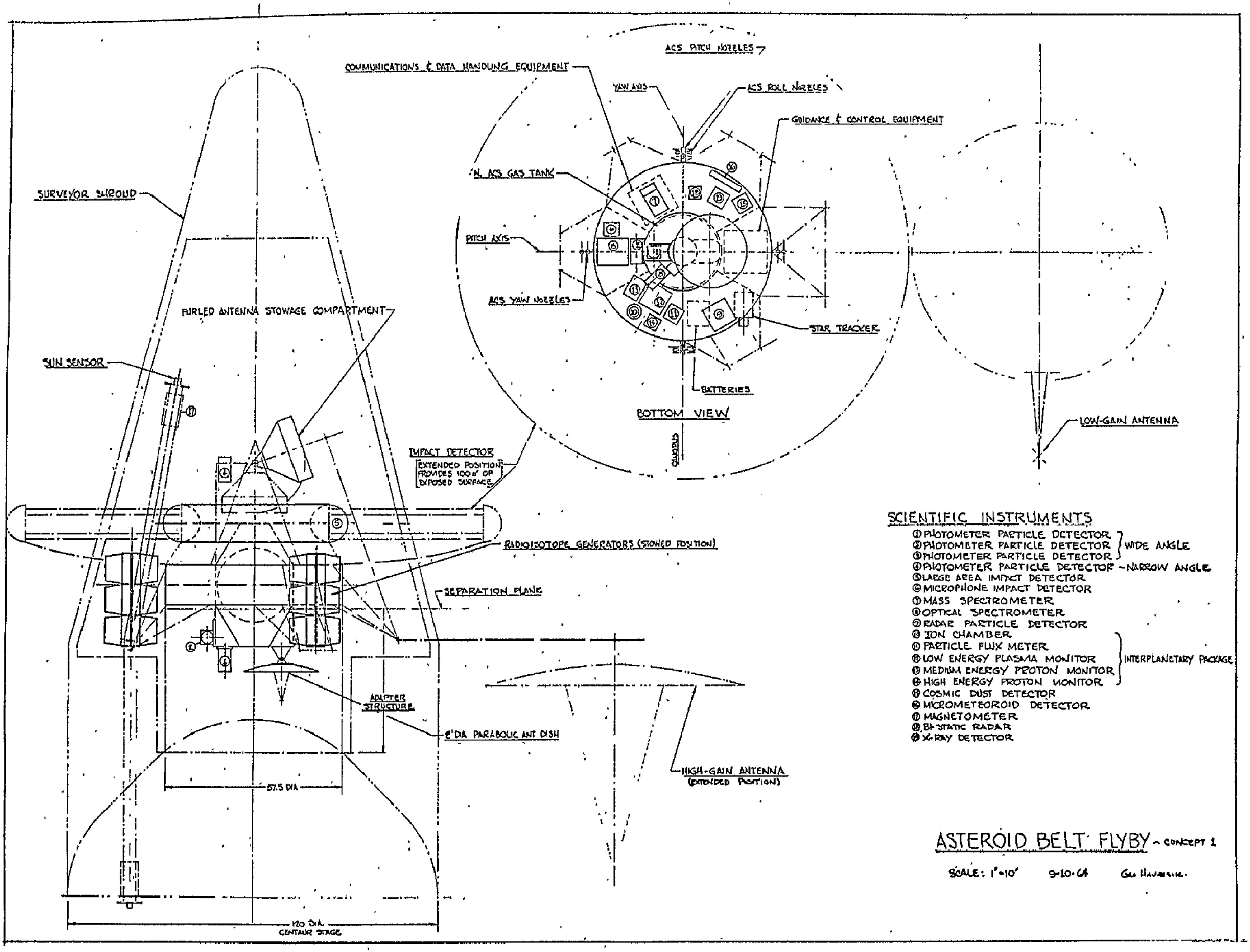
Payload versus characteristic velocity for several typical booster systems are shown. The effect on performance of using a high energy third stage is indicated by curves 1, 2 and 7. A typical Jupiter mission is shown indicating a trip time difference of approximately one year. The choice of booster to be used will depend on a trade-off between the effects of trip time, design payload and booster availability.

JAAB FLYBY~BOOSTER CAPABILITY

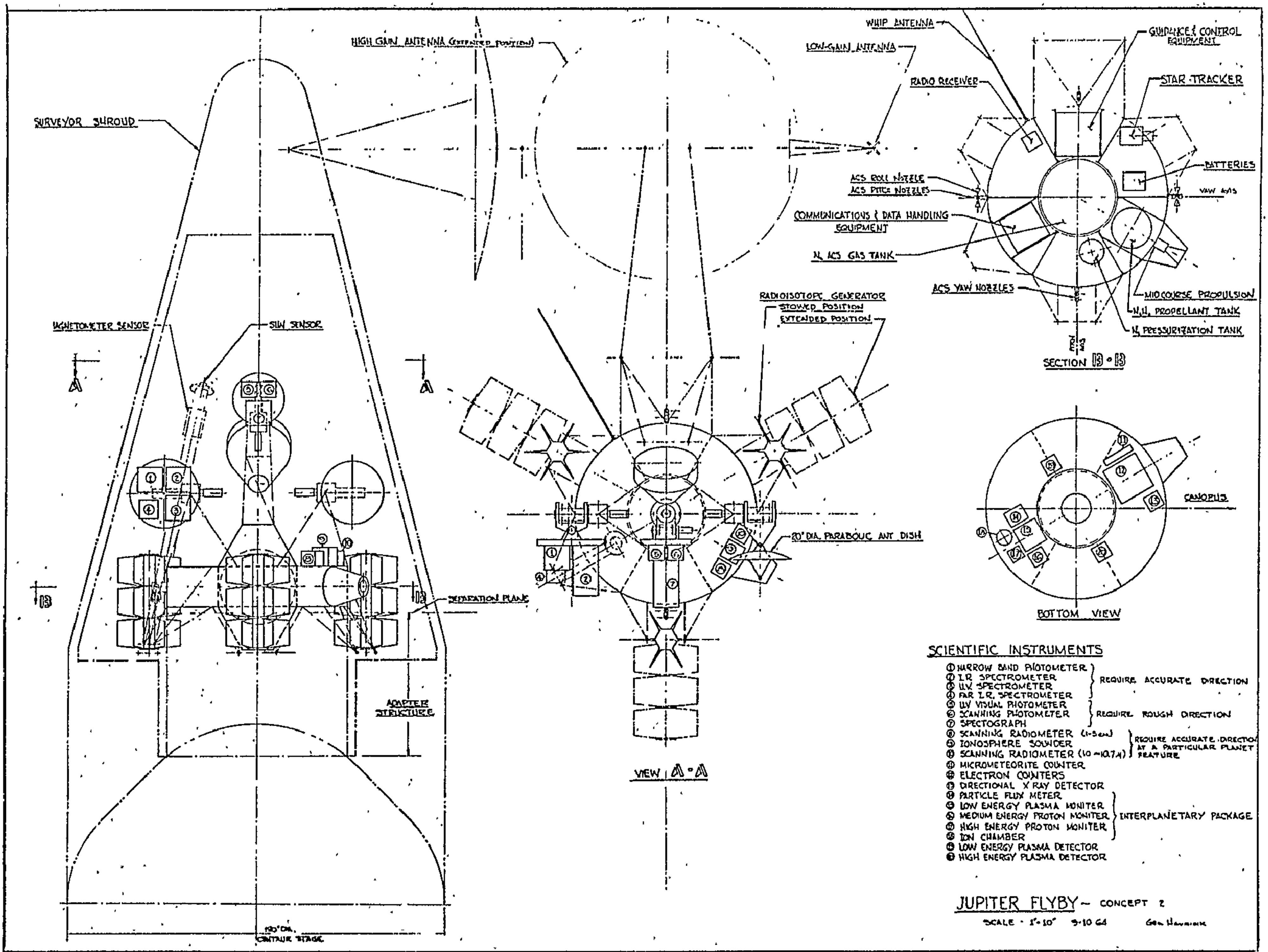


PRELIMINARY SPACECRAFT CONCEPTS

The next two figures illustrate spacecraft design concepts for the Asteroid Belt and Jupiter missions, based on the minimum available volume (Centaur and Surveyor shroud combination). Both designs incorporate a 7 ft parabolic unfurlable antenna and nine SNAP-9A type radioisotope power generators. The particle detector for the Asteroid Belt mission consists of four sheets of polyester film representing 100 ft^2 of surface area when extended. The erection mechanism would be similar to that for the unfurlable antenna. The stowed weight of the detector is 110 lb.



SURVEYOR SHROUD
FURLED ANTENNA STOWAGE COMPARTMENT
SUN SENSOR
IMPACT DETECTOR
EXTENDED POSITION PROVIDES 100 ft² OF EXPOSED SURFACE
RADIOISOTOPE GENERATORS (STOWED POSITION)
SEPARATION PLANE
ADAPTER STRUCTURE
2' DIA PARABOLIC ANT DISH
57.5 DIA
120 DIA CENTAUR STAGE
HIGH-GAIN ANTENNA (EXTENDED POSITION)
ACS PITCH NOZZLES
COMMUNICATIONS & DATA HANDLING EQUIPMENT
YAW AXIS
ACS ROLL NOZZLES
GUIDANCE & CONTROL EQUIPMENT
N₂ ACS GAS TANK
PITCH AXIS
ACS YAW NOZZLES
STAR TRACKER
BATTERIES
BOTTOM VIEW
LOW-GAIN ANTENNA
SCIENTIFIC INSTRUMENTS
① PHOTOMETER PARTICLE DETECTOR
② PHOTOMETER PARTICLE DETECTOR
③ PHOTOMETER PARTICLE DETECTOR
WIDE ANGLE
④ PHOTOMETER PARTICLE DETECTOR ~NARROW ANGLE
⑤ LARGE AREA IMPACT DETECTOR
⑥ MICROPHONE IMPACT DETECTOR
⑦ MASS SPECTROMETER
⑧ OPTICAL SPECTROMETER
⑨ RADAR PARTICLE DETECTOR
⑩ ION CHAMBER
⑪ PARTICLE FLUX METER
⑫ LOW ENERGY PLASMA MONITOR
⑬ MEDIUM ENERGY PROTON MONITOR
⑭ HIGH ENERGY PROTON MONITOR
INTERPLANETARY PACKAGE
⑮ COSMIC DUST DETECTOR
⑯ MICROMETEOROID DETECTOR
⑰ MAGNETOMETER
⑱ BI-STATIC RADAR
⑲ X-RAY DETECTOR
ASTEROID BELT FLYBY ~ CONCEPT 1
SCALE: 1"=10"
9-10-64



SURVEYOR SHROUD
HIGH GAIN ANTENNA (EXTENDED POSITION)
WHIP ANTENNA
LOW-GAIN ANTENNA
RADIO RECEIVER
GUIDANCE & CONTROL EQUIPMENT
STAR TRACKER
BATTERIES
ACS ROLL NOZZLE
ACS PITCH NOZZLES
YAW AXIS
COMMUNICATIONS & DATA HANDLING EQUIPMENT
N_2 ACS GAS TANK
ACS YAW NOZZLES
MIDCOURSE PROPULSION
N_2H_4 PROPELLANT TANK
N_2 PRESSURIZATION TANK
SECTION B-B
RADIOISOTOPE GENERATOR
STOWED POSITION
EXTENDED POSITION
MAGNETOMETER SENSOR
SUN SENSOR
A
A
CANOPUS
20" DIA. PARABOLIC ANT DISH
B
B
SEPARATION PLANE
BOTTOM VIEW
ADAPTER STRUCTURE
VIEW A-A
120" DIA. CENTAUR STAGE
SCIENTIFIC INSTRUMENTS
① NARROW BAND PHOTOMETER
② I.R. SPECTROMETER
③ U.V. SPECTROMETER
④ FAR I.R. SPECTROMETER
REQUIRE ACCURATE DIRECTION
⑤ U.V. VISUAL PHOTOMETER
⑥ SCANNING PHOTOMETER
⑦ SPECTOGRAPH
REQUIRE ROUGH DIRECTION
⑧ SCANNING RADIOMETER (1-5cm)
⑨ IONOSPHERE SOUNDER
⑩ SCANNING RADIOMETER (10-10.7μ)
REQUIRE ACCURATE DIRECTION AT A PARTICULAR PLANET FEATURE
⑪ MICROMETEORITE COUNTER
⑫ ELECTRON COUNTERS
⑬ DIRECTIONAL X RAY DETECTOR
⑭ PARTICLE FLUX METER
⑮ LOW ENERGY PLASMA MONITER
⑯ MEDIUM ENERGY PROTON MONITER
⑰ HIGH ENERGY PROTON MONITER
⑱ ION CHAMBER
INTERPLANETARY PACKAGE
⑲ LOW ENERGY PLASMA DETECTOR
⑳ HIGH ENERGY PLASMA DETECTOR
JUPITER FLYBY ~ CONCEPT 2
SCALE - 1"=10" 9-10 64

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